

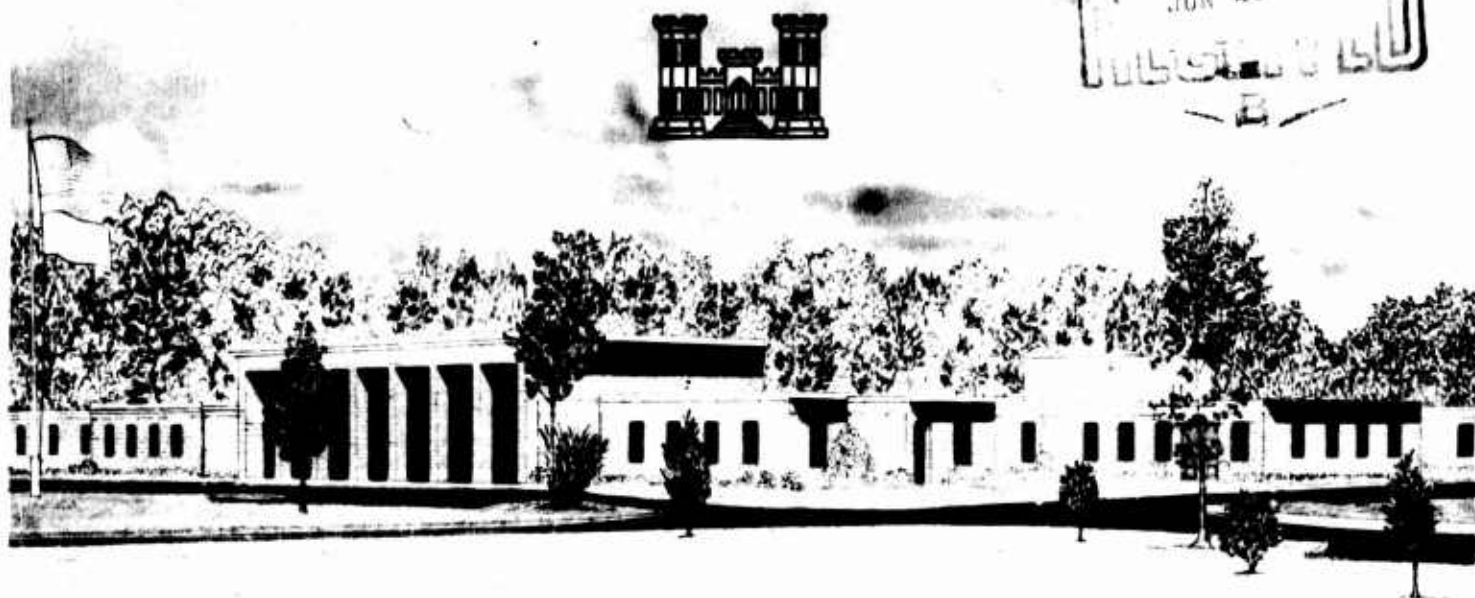
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TECHNICAL REPORT N-70-10

**SURVEY OF GULF COAST
STRUCTURAL DAMAGE RESULTING FROM
HURRICANE CAMILLE, AUGUST 1969**

Final Report



April 1970

Conducted for Office of Civil Defense, Office of the Secretary of the Army
Washington, D. C. 20310

Under Work Order No. DAHC20-68-W-0192, Work Unit 1127E

By U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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by

M. E. Criswell, R. S. Cummins



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OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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ARMY-MRC VICKSBURG, MISS.

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SUMMARY

Hurricane Camille, a relatively small but very intense tropical storm, struck and heavily damaged the Mississippi River Delta area below New Orleans, Louisiana, and the Mississippi Gulf Coast area on late 17 August 1969. The storm center came ashore near Pass Christian, Mississippi. Winds reportedly in excess of 190 mph and tides at least 16 feet above normal and with large wind-driven waves accompanied Camille and caused extensive damage to structures located along its path.

This report describes in qualitative terms and with photographs the damage to structures seen by an OCD-sponsored inspection team. This team consisted of the authors and two staff members from URS Corporation sent to the damaged areas on 22-26 August.

The damage in the Mississippi Delta area was primarily caused by high water moving in from the Gulf of Mexico to the east. Flooding was very severe over large areas.

The low-lying areas of the Mississippi Gulf Coast immediately along the shoreline were most heavily damaged. Damage in these areas appeared to have been primarily a result of the battering from wind-driven waves riding atop the high water. A distinct debris line was often seen marking the limit of wave damage. Damage from wind was visible along the coast and extended inland along Camille's path. Much of the wind damage resulted from the falling of trees and branches onto structures, highways, and overhead lines.

Much masonry (block) construction along the coast collapsed completely, probably when the first-floor bearing walls failed. Older wooden frame residences along the coast often withstood the storm comparatively well. Damage in downtown Gulfport and Biloxi was primarily limited to water damage, and damage to signs, awnings, and lightly constructed buildings. No sizable multistory building seen which received only wind loading collapsed from inadequate lateral resistance.

Based on the storm damage observed, the following conclusions were reached:

1. Many low buildings, especially masonry structures, are too

dependent upon vertical loads and forces for their stability; their resistance to lateral loads is small.

2. Connections and other "details" essential for the building components to act together as a structure are too often given inadequate attention by both designer and builder. Need for adequate inspection during construction was also indicated.

3. The possibility of any hurricane loading did not appear to have been adequately recognized in the design of much recent construction in the coastal areas. However, designing structures in the immediate coastal areas to survive with little or no damage the winds and water action of unusual storms such as Camille may not be economically feasible.

4. Primarily because of the uncertainties concerning the loads acting on most of the structures in the storm area, quantitative information on the strength and performance of these buildings will be difficult to determine.

5. The preponderance of water damage in many areas and the lack of overpressure loadings and ground motion preclude the direct projection of the storm damage to predict the damage from a nuclear blast loading.

ABSTRACT

This report describes the damage to structures seen by an inspection team sent to the Mississippi and Louisiana Gulf Coast regions after Hurricane Camille, a very violent but relatively small tropical storm, came ashore west of Gulfport, Mississippi, late on 17 August 1969. Many photographs of the storm damage are included.

Extensive damage resulted both from the unusually high winds accompanying Camille and from the extremely high tides coupled with wind-driven waves. Damage was greatest in low areas immediately adjacent to the coastline.

Because of uncertainties of the material properties for the various buildings and particularly of the loading, the report presents mainly qualitative results.

More ductile buildings, such as heavy wooden frame construction, appeared to have survived the storm best.

The storm damage indicated a need for more lateral strength in buildings, especially masonry structures, and for more adequate design of connections and other details.

PREFACE

This report was prepared by Messrs. Marvin E. Criswell and Reid S. Cummins under the general supervision of Mr. G. L. Arbuthnot, Jr., Chief, Nuclear Weapons Effects Division, and under the direct supervision of Mr. W. J. Flathau, Chief, Protective Structures Branch, U. S. Army Engineer Waterways Experiment Station.

The report is primarily a trip report of the inspection trip made by the authors and two professional staff members of the URS Corporation to the Gulf Coast regions heavily damaged by Hurricane Camille in August 1969. This inspection trip was sponsored by the Office of Civil Defense (OCD) under the direction of Dr. J. O. Buchanan, Deputy Assistant Director of Civil Defense (Research), through Mr. R. F. Stellar, Chief of the Joint Civil Defense Support Group of the Office, Chief of Engineers.

The authors wish to acknowledge Mr. James F. Halsey and Dr. Carl F. Miller, party members from URS, for their assistance both during and after the trip; the New Orleans District, Corps of Engineers, for their aid and for permission to use Figures 2.10 through 2.13 and 2.25 through 2.27; and the Weather Bureau at New Orleans for providing meteorological information on Camille.

Director of the Waterways Experiment Station during the preparation of this report was COL Levi A. Brown, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	25.4	millimeters
feet	0.3048	meters
pounds (force) per square inch	6894.757	newtons per square meter
inches of mercury (32 F)	3386.389	newtons per square meter
miles (U. S. statute)	1.609344	kilometers
miles (U. S. statute) per hour	1.609344	kilometers per hour

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Hurricane Camille, the third tropical Atlantic storm of 1969, struck the United States mainland during the late hours of Sunday, 17 August 1969, coming ashore along the Mississippi Gulf Coast. With winds reportedly approaching or exceeding 200 mph* near the eye of the storm at the time it came aground, it was reported to be the most intense, although not the largest, hurricane ever to hit the United States mainland. There was extensive water and wind damage to the Mississippi Gulf Coast and to the Mississippi River Delta below New Orleans, Louisiana, with considerable wind damage extending along the storm's path inland.

On 20 August, Dr. J. O. Buchanan (Office of Civil Defense, Research) requested that Office, Chief of Engineers (OCE) provide support from the U. S. Army Engineer Waterways Experiment Station (WES) to aid in conducting an OCD-sponsored survey of the storm damage.

1.2 SCOPE AND PURPOSE

In a telephone call on 21 August among Mr. W. J. Flathau and LTC F. M. Anklaam (WES) and Messrs. F. Heller and R. Stellar (OCE), WES was requested to provide transportation (both air and ground) and professional assistance ". . . to aid OCD contract personnel in making an aerial reconnaissance of the disaster area, obtaining representative photographic coverage, and related work. . . ." starting on 22 August.

The field party included two professional staff members of the URS Corporation, Burlingame, California: Mr. James F. Halsey, Director, Theoretical and Applied Mechanics; and Dr. Carl F. Miller, Vice-President and Director, Resource Allocations Research Program. WES representatives were Messrs. R. S. Cummins and M. E. Criswell, Research Structural Engineers, and Mr. George Newman, Photographer.

* A table of factors for converting British units of measurement to metric units is presented on page 9.

The purpose of the survey was as follows:

1. Survey the damage caused by the storm, especially to buildings, utilities, and other life-supporting systems, and the cleanup and recovery operation and organization.

2. Relate these findings to possible damage from a nuclear blast and the postattack recovery and/or suggest research needed to accomplish this.

The WES personnel were particularly concerned with the structural performance of civil engineering structures and other buildings located in the storm-damaged area. Therefore, this report will discuss primarily the damage to structures resulting from Hurricane Camille, especially to those along the Mississippi Gulf Coast.

1.3 INSPECTION TEAM ITINERARY

1.3.1 22 August. The inspection team left the Vicksburg Airport, Vicksburg, Mississippi, at 7:00 a.m. aboard a chartered, six-passenger aircraft for New Orleans. The team arrived at the New Orleans District (NOD), Corps of Engineers, office at approximately 9:00 a.m. During this visit, MAJ West, Executive Officer, and his staff presented an excellent briefing regarding the damaged areas within the NOD (mainly below New Orleans), and were most helpful in offering their support.

During the afternoon of 22 August, an aerial reconnaissance was made of damage in the Mississippi River Delta area (particularly Plaquemines Parish). Figure 1.1 shows the flight path and itinerary.

Turbulent weather moving in from the north and east prevented flight over the Mississippi Gulf Coast area. After stops at Houma and Hammond, Louisiana, due to the unfavorable weather conditions, the party continued the flight to Hattiesburg, Mississippi. In Hattiesburg the party met with other WES personnel who had brought in supplies and ground vehicles from Vicksburg.

1.3.2 23 August. Poor visibility precluded flying on the morning of 23 August; therefore, the party left Hattiesburg by automobile bound for the Gulf Coast.

Personnel of the Office of Emergency Preparedness (OEP) and the U. S. Army Engineer District, Mobile, located in the Operation Center at the

Gulfport Airport, and the Harrison County OCD Director, Mr. Wade Guice, were contacted and advised of the party's mission.

A brief tour by automobile was made of the storm-damaged area along U. S. Highway 90 from the Gulfport downtown area west to Bay Saint Louis. On the afternoon of 23 August, the party departed the Gulfport Airport for an additional aerial survey of the damaged areas. Unfavorable weather prevented flight east of Gulfport and over Biloxi and Pascagoula, but before returning to Hattiesburg, several Mississippi inland towns (Picayune, Poplarville, Lumberton, and Purvis) along the path of the storm were viewed from the air.

1.3.3 24-25 August. On 24 August, Mr. Halsey and Dr. Miller left the inspection team for a flight to Washington, D. C., to attend a conference at OCD regarding this survey.

The WES personnel returned to the Gulfport area by automobile for closer inspection of selected damaged structures and to make a general damage survey in the Biloxi area, including the Back Bay vicinity.

1.3.4 26 August. On 26 August, WES personnel returned to Vicksburg by automobile.

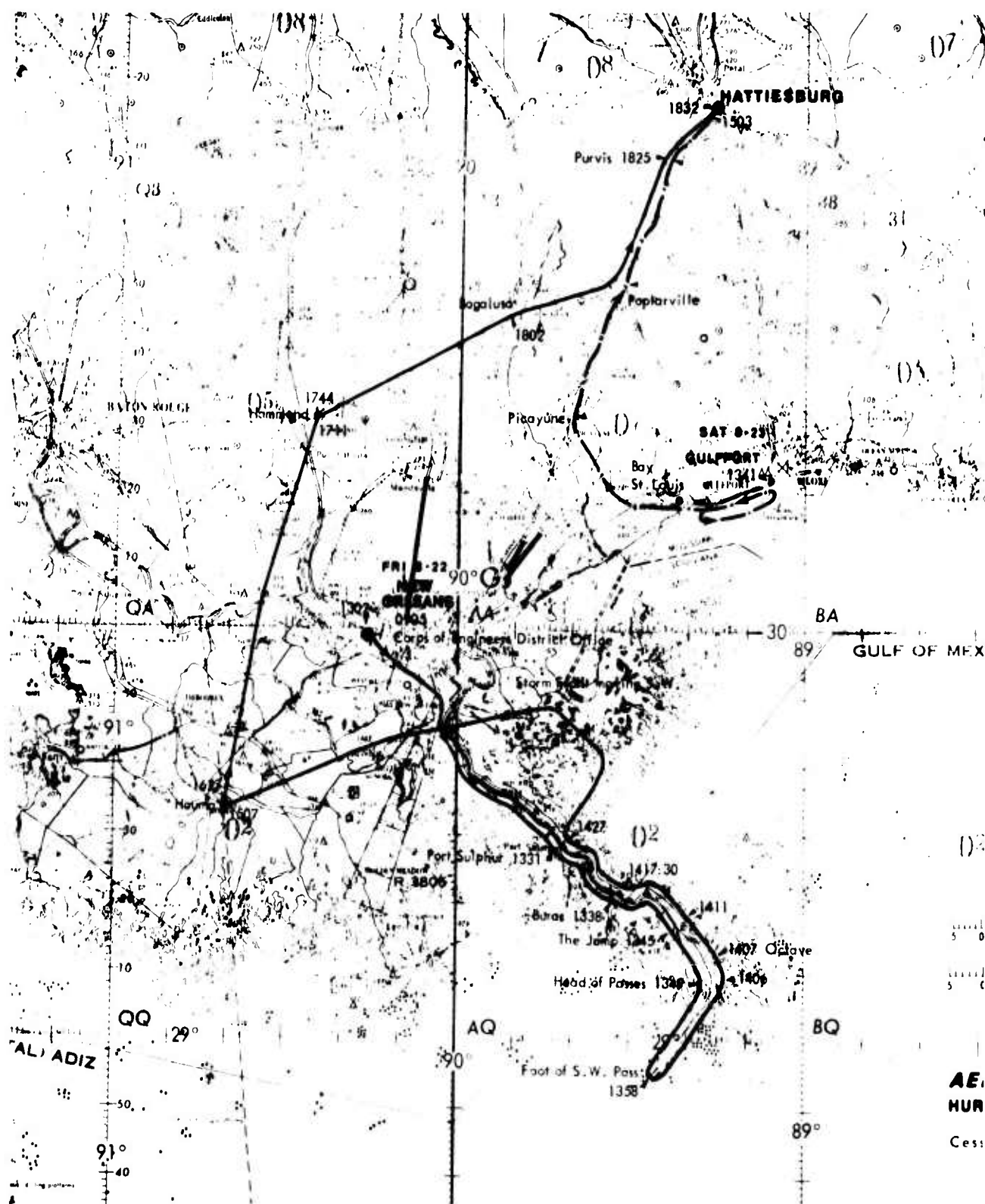
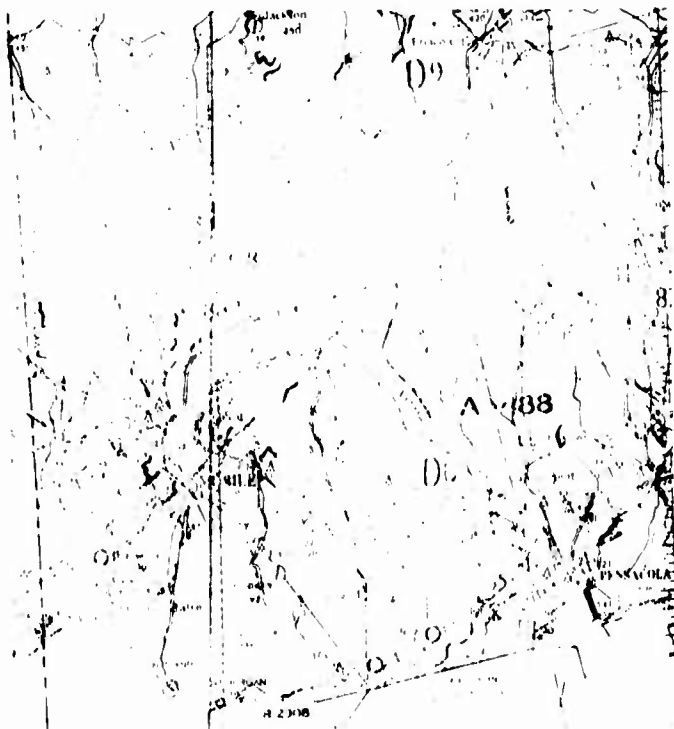


Figure 1.1 Flight itinerary and route.



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AIRIAL RECONNAISSANCE ROUTE

HURRICANE CAMILLE • 22-23 AUGUST 1969

on Super Skywagon

88°

1

CHAPTER 2

DAMAGE TO STRUCTURES FROM HURRICANE CAMILLE

2.1 THE STORM

Camille, spawned as a tropical storm in the Caribbean Sea on 14 August 1969, gained strength rapidly as it touched western Cuba and developed into a very intense storm as it entered the Gulf of Mexico (Reference 1). It came ashore about 10:00 p.m. CST on the night of 17 August 1969 along the Gulf Coast of Mississippi, centering its fury in the vicinity of Pass Christian. The highest tides and winds and the lowest barometric pressure ever recorded along the Gulf Coast resulted from Camille. Winds estimated at 190 mph or greater generated 10- to 12-foot seas atop at least 16-foot tides in many areas. A high-water mark at 24.2 feet above mean sea level was measured east of the Pass Christian business district (Reference 2). Local tornadic winds also were reported in the storm area. Figure 2.1 shows the path and the estimated wind field of Camille (Reference 3). An extremely low barometric pressure of 26.61 inches of mercury was measured in the eye of the storm at 12:15 CST on 17 August, the second lowest pressure ever recorded on or near the United States mainland. A verified pressure reading of 26.85 inches of mercury was measured in the Bay Saint Louis area.

The water level generally changed slowly with continuous wave action rather than one large tidal wave; however, some observers reported localized areas which apparently suffered rapid rise and/or fall of the water level.

As shown in Figure 2.2, the winds from Camille far exceeded the listed 100-year wind intensity of about 110 mph along the Gulf Coast (Reference 4).

The storm moved through the coastal area at a speed of about 15 mph, traveling in a north by northwesterly direction, passed to the west of Hattiesburg, Mississippi, then turned north and continued through the state. Maximum wind velocity had dropped to 67 mph and a minimum barometric pressure of 28.93 inches was recorded as the storm passed to the east of Jackson, Mississippi. Moderate to heavy rains accompanied

the storm as it passed through the state.

Camille, reduced to a low-pressure depression in northern Mississippi, moved northward through Tennessee and into Kentucky, then turned eastward (Figure 2.3). Camille continued to vent its fury in the form of torrential rains in Virginia and West Virginia, causing disastrous local flooding and numerous deaths in the area near the James River.

2.2 GENERAL DESCRIPTION OF STORM DAMAGE

The most intense damage from Camille was in Plaquemines Parish, Louisiana (below New Orleans), and in the first several blocks inland along the Mississippi Gulf Coast. It appeared that damage in these areas resulted primarily from high water and wind-driven wave action. Structures were completely leveled along some of the coastal areas.

Flooding without the destructive pounding from wave action and water movement was evident in many low areas several blocks inland, particularly in the east end of Biloxi, which was afforded protection by the proximity of Deer Island.

Wind damage along the coast, though certainly not negligible, was generally secondary to the damage from water and water movement. The wind damage in inland areas was generally less than this inspection team had expected. The 190-mph winds reported correspond to a dynamic wind load of approximately 0.85 psi. Most of the structures, however, were not subjected to winds of this magnitude because trees, adjoining structures, and other objects causing ground drag prevented their being loaded with the maximum wind load. Also, the wind velocity was less in areas away from the storm center and the winds dissipated considerably as Camille moved inland (see Figure 2.1).

Although less than one week elapsed from the time of the storm until this inspection trip, much debris had already been cleared from highways and streets, plywood had been removed from most windows, and much broken glass had been replaced. Some evidence of these operations can be seen in the photographs contained herein.

2.2.1 Mississippi River Delta, Louisiana. Damage observed from the air appeared to have been caused almost entirely by high water and wave

action driven across the delta marshland from an easterly direction over the Mississippi River levees. Many areas were still flooded at the time of this inspection trip.

The damage was greatest from Empire to Venice, an area where only a narrow strip of low-lying marshland separated the communities along the Mississippi River from Breton Sound, a part of the Gulf of Mexico, to the northeast. Figure 2.4 is a map of this area.

Many mobile homes (brought in after Hurricane Betsy in 1965) and small houses in this area were completely destroyed. In numerous cases, these structures were floated fairly intact onto or past the back levee located behind the river towns. Both the front and back levees were damaged, especially between Buras and Venice. Figures 2.5 through 2.9 are photographs taken by the survey team in the Empire-Buras area. Figures 2.10 through 2.13 are photographs taken on 19-20 August 1969 by personnel of the New Orleans District, Corps of Engineers (NOD).

Most of the structures in this area were either light single-family dwellings or heavy industrial (oil, sulphur, shipping) construction. From the air, the industrial construction usually appeared to have remained structurally intact.

2.2.2 Mississippi Gulf Coast. A large portion of, and the most impressive, storm damage paralleled the Mississippi Gulf Coast and extended from one to several blocks inland, depending on the local topography. This damage it would seem resulted primarily from rising water and wave action.

The wind directions in the Gulf Coast area changed continually as Camille with its counterclockwise winds moved northward. The maximum winds in the Gulfport area appeared to have been from the east. The tidal rise and wave action apparently came from the south to southeast.

A map of the central Mississippi Gulf Coast area is shown in Figure 2.14. The most heavily damaged areas visited by this team included the Pass Christian vicinity, parts of Long Beach, and local waterfront areas between the Biloxi and Gulfport business districts. Aerial views of the area from Gulfport west are contained in Figures 2.15 through 2.27. Figures 2.25 through 2.27 were taken on 19 August 1969 by NOD. The coastal

area immediately north and west of the Port of Gulfport was somewhat sheltered by the port facilities.

All of the coastal area along U. S. Highway 90 from Saint Louis Bay to Biloxi Bay, a distance of 27 miles, was built up with a variety of construction types including many large, old residences and several multistory resort hotels, motels, and apartments, as well as gasoline stations, restaurants, and retail stores.

Many motels and apartments were completely leveled. Many older and multistory houses remained standing, even though they sustained extensive structural damage at the first floor level primarily from the effects of high water and the pounding of waves. In many cases, the contents of the first floor were washed out. A large portion of the heavily damaged structures, especially the older residences, that remained standing will probably be torn down as restoration will be either impossible or uneconomical.

Numerous trees were down in the coastal area. Bark was off the seaward side of many trees 12 to 15 feet from the ground, indicating the upper level of wave action and effects of waterborne debris.

The extent of debris deposited inland marked the limit of greatest tidal action. The debris line is clearly seen in Figure 2.17.

Many small boats and several barges and storage tanks floated ashore, some leaving considerable structural damage in their path. Large rolls of kraft paper and bales of jute came inland from the Port of Gulfport facilities. Three large freighters were floated aground in the Port facilities.

The downtown area of Gulfport and inland coastal areas had only comparatively small amounts of structural damage. In the downtown area of Gulfport, some windows and signs were broken and many first floor areas suffered water damage. The post office, only one block from the coastal highway (U. S. 90), appeared undamaged except for water in the partial basement, the location of a NFSS Fallout Shelter. In other areas of Gulfport, some lightly constructed buildings and roofs were blown over with window breakage and roof damage quite common. Isolated pockets of residences inland were heavily damaged, with some homes leveled, probably by local tornadic winds.

Water damage along the Back Bay of Biloxi was less than that along the

coast, probably because it was protected from the pounding wave action, but flooding was still very severe.

Some general damage photographs of the Mississippi coastal region are contained in Figures 2.28 through 2.39.

2.2.3 Inland Areas. The main inland damage visible from the air was to trees, light utility buildings, house trailers, and roofs, especially corrugated metal roofs.

In the path of the storm, some larger buildings, especially school gymnasiums and long-span steel frame buildings, were damaged. A considerable portion of the structural damage to residences was caused by falling trees.

2.3 PERFORMANCE OF STRUCTURAL TYPES

Some types of structures withstood the wind and water forces much better than others. Failure modes of various structural types also varied considerably.

Survival of the structures was primarily governed by the ability of the building to resist lateral loads and the care taken with the design and construction details.

Specific case studies will be discussed in Chapter 3.

2.3.1 Masonry Block Structures. Many motels, apartments, gasoline stations, and small businesses along the Gulf shoreline were constructed of block and/or brick bearing walls, and these structures generally fared very poorly. An appreciable number collapsed totally with little evidence remaining to indicate how they looked before the storm. Almost all buildings of this type were totally destroyed in the area along the coast from Gulfport to Bay Saint Louis. Figures 2.40 through 2.46 show the remains of some buildings of this type.

Masonry block buildings were usually either totally destroyed or left relatively unharmed, a behavior expected because of the brittle nature of nonreinforced or very lightly reinforced block walls. A few block buildings had only the south or east portions destroyed.

Block walls are inherently weak in resisting tension or bending, loading cases necessarily accompanying the water and wind movement. Block

buildings have little "give" or ductility. Many block buildings along the Gulf Coast probably failed when the walls were destroyed and the rest of the structure, being inadequately supported, collapsed and came apart like a house of dominoes. The debris from the block buildings was usually of fairly small size, many individual blocks and pieces having a largest dimension of 4 feet or less.

Figure 2.43 shows the remains of the Richelieu Apartments, where 23 people died after ignoring repeated warnings by local authorities to vacate the building.

Block buildings inland generally suffered little damage except where very slender walls were used.

2.3.2 Wooden Frame Buildings. Many two- and three-story older frame residences lined the coast, especially west of Long Beach and between Gulfport and Biloxi. Many withstood the storm forces amazingly well. Depending on the location, many were totally leveled or destroyed (Figures 2.47 and 2.48), but others remained standing even after very extensive structural damage to the first floor area (Figure 2.49). Survival in the top floors of many older wooden frame buildings would have been possible in many cases when so-called modern buildings in the area were totally destroyed.

These older buildings were tied together much better than the masonry structures, functioned much more as a unit, and were much less dependent on deadweight for their stability. Well constructed wooden buildings are generally very ductile in behavior; they can withstand large movements before collapsing. Also, the diagonal sheeting on the exterior and the numerous interior walls capable of functioning as shear walls and load-bearing walls helped these buildings withstand the lateral loads produced by the storm.

Many wooden frame structures, especially older residences, were not designed by analysis but were built based on experience and intuition to have "sufficient strength" using convenient and available material sizes. If these buildings were structurally analyzed, many no doubt would be found to have very high factors of safety for normal design loads. These non-designed (from an analysis standpoint) wooden structures probably ranged from

the most underdesigned to the most overdesigned structures in the area.

Along the Gulf Coast and especially in the Mississippi River Delta, many wooden buildings were lifted from their foundations and transported relatively intact by the water for appreciable distances.

The behavior of wooden frame structures inland, those receiving only wind loading, varied considerably. Most withstood the wind loads fairly well. Those damaged were usually very lightly constructed (such as utility buildings), deteriorated, or inherently weak, and often had relatively large wall-free interiors (e.g. stores, garages, and farm buildings).

2.3.3 Light Steel or Concrete Frame Buildings. A considerable number of single-story stores, warehouses, and shops were located along the coast which were constructed with steel frames, nonstructural masonry or sheet metal exterior walls, small roof beams or bar joists, and built-up roofing.

Along the coastline, the walls of most of these buildings failed before the frame itself, and the contents of the building were washed out. The bare frame was often left, sometimes with the steel columns noticeably out of plumb. Figure 2.50 shows a steel frame building in Gulfport. Some frames and portions of the roofs collapsed when bar joists supporting the roofs were not adequately connected at their ends.

Figures 2.51 and 2.52 show two gutted frame structures, and another such structure will be discussed in Chapter 3.

Small concrete frame buildings were not numerous. The walls and roofs usually failed before the frame. Figure 2.53 shows one such building.

Inland, the wind damage to these structures was primarily limited to window breakage, and damage to some sheet metal walls and to roofs.

2.3.4 Heavier Business and Multistory Construction. The heavier frame and masonry structures, such as the multistory hotels and structures in the downtown areas of Biloxi and Gulfport, usually sustained only superficial structural damage, i.e. damage to windows, signs, awnings, nonstructural exterior walls and screens, and water damage in basements and at first floor levels. A view of Gulfport from the south is shown in Figure 2.54.

One of the few newer tall buildings in the area was the eight-story concrete frame building of the Mississippi Power Company. It is located

immediately inland from U. S. Highway 90 in Gulfport and is visible in the background of Figure 3.28. This building had double-glazed windows of large size and sat on an elevated plaza. The only damage was a few broken window panes and damage to the east side of the screen around the penthouse and cooling tower.

In no cases seen did large multistory buildings suffer from overall lateral instability or overturning. Several older hotels and a bank building were up to eight or nine floors high. Many of these buildings have "nonstructural" interior partitions and walls which acted efficiently to help resist lateral loadings.

2.3.5 Buildings with Large Interior Areas: Schools, Churches, and Gymnasiums. Most churches and schools in the Biloxi-Gulfport area suffered only comparatively minor damage. This was not a common type of building along the immediate coastal regions. The front of one fairly large, heavy, wooden frame church located immediately along the coast in Long Beach (Saint Thomas Catholic Church) was destroyed, probably by wave action.

Inland, some wind damage to churches and schools was observed. In several cases, the wind force had been sufficient to blow in the tall masonry walls and/or the roofs at the east ends of church naves and gymnasiums.

The Poplarville High School was heavily damaged (see Figure 2.55).

2.3.6 Marine Structures and Bridges. Nearly all piers and boat docks along the Gulf Coast were totally destroyed. The piling, which was often tilted toward land, was all that remained of most of the piers. Figure 2.56 shows part of the Pass Christian Yacht Club facility after the storm.

No significant damage to the seawall extending from Bay Saint Louis to Biloxi Bay was seen by this team.

Levees were breached and washed out in several locations along the Mississippi River below New Orleans.

All bridges observed had sustained some damage but none had collapsed. The D'Iberville Bridge north of Biloxi on Back Bay sustained damage when free-floating barges struck it. The railroad bridge over Saint Louis Bay, a multispans causeway, had the rails and ties stripped from it by high water and wave action. The Bay Saint Louis highway bridge had extensive damage to the deck and will be discussed in detail in Chapter 3.

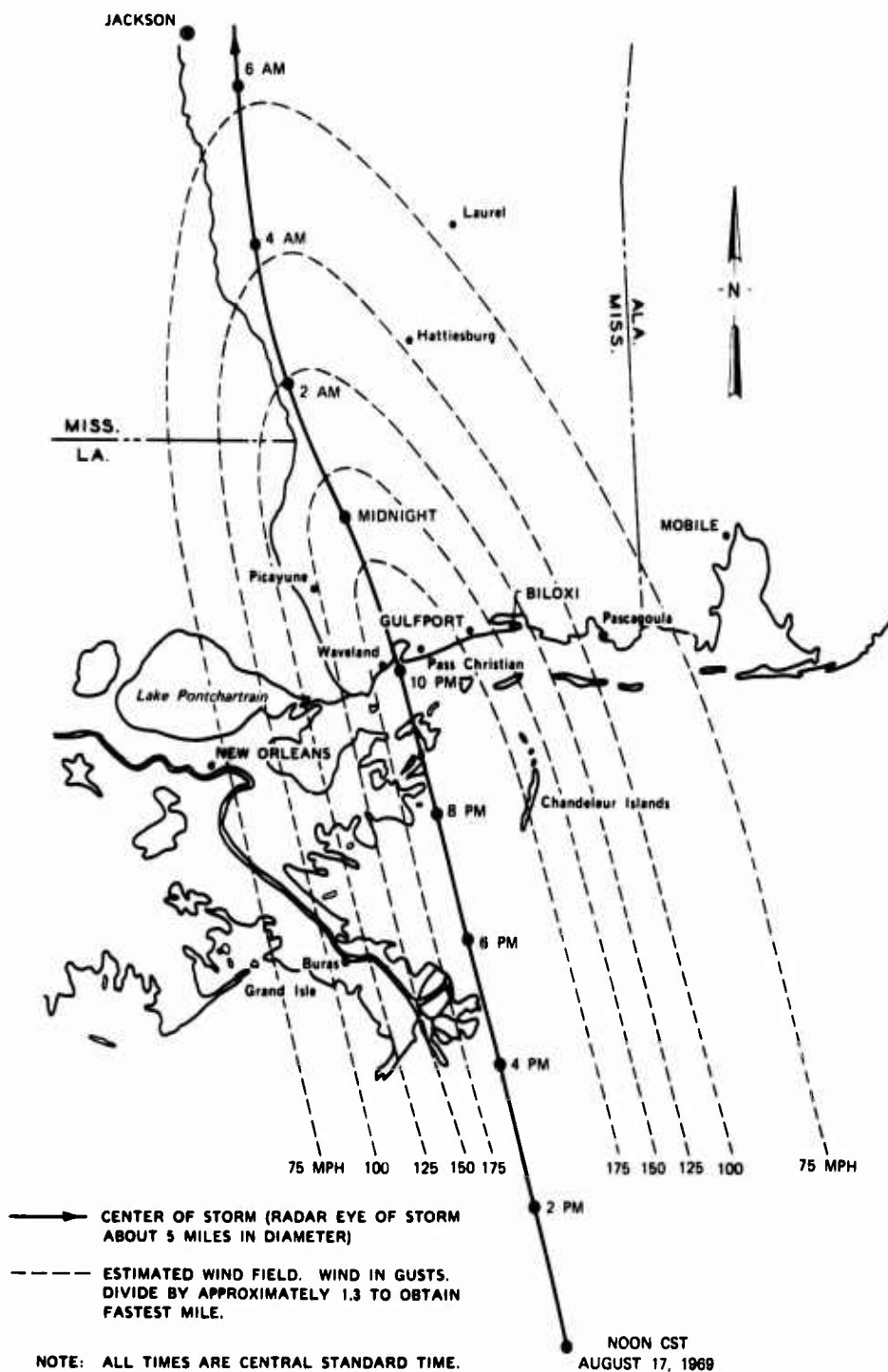


Figure 2.1 Hurricane Camille's path and winds (from New Orleans Weather Bureau).

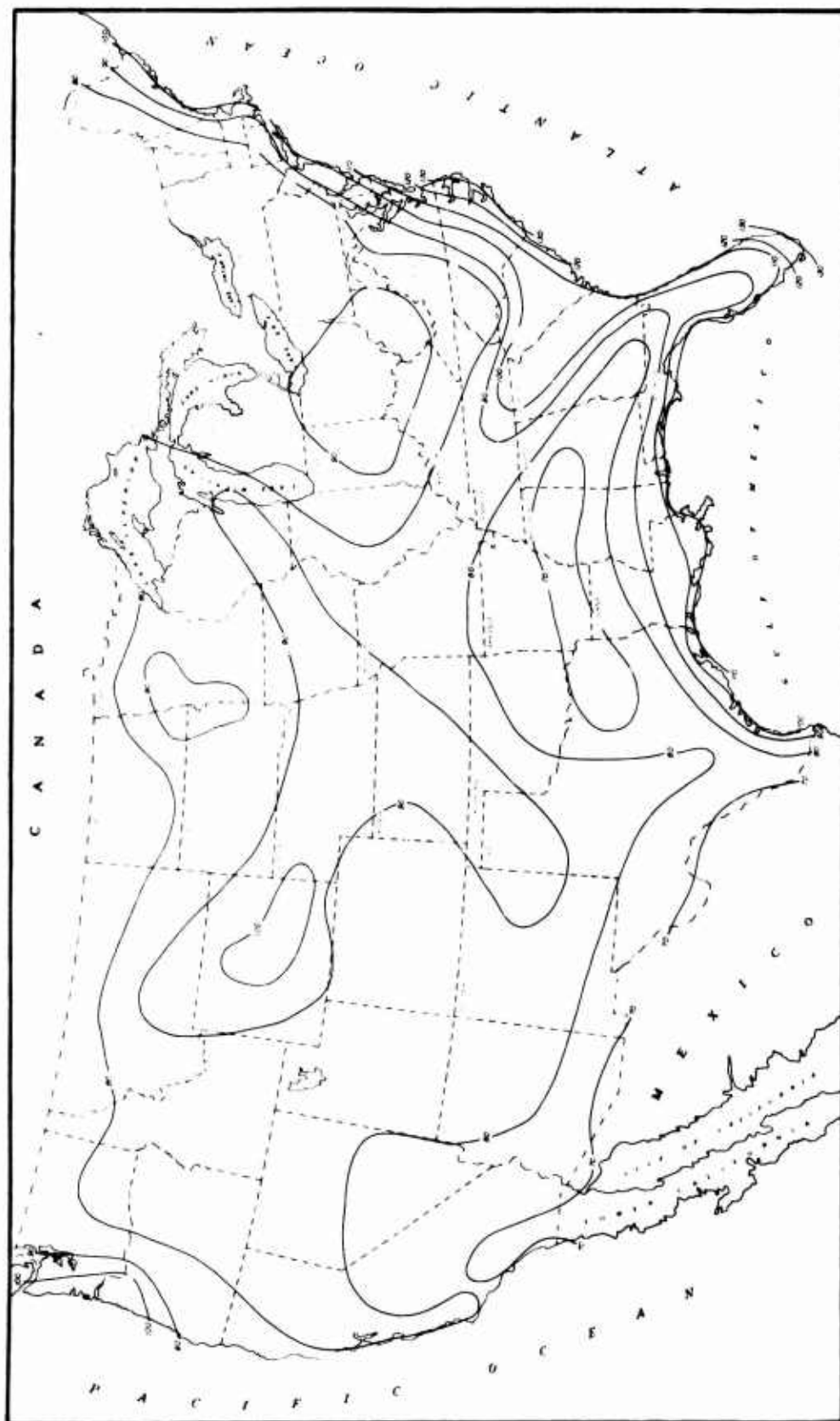


Figure 2.2 Fastest winds, miles per hour, 100-year period of recurrence.

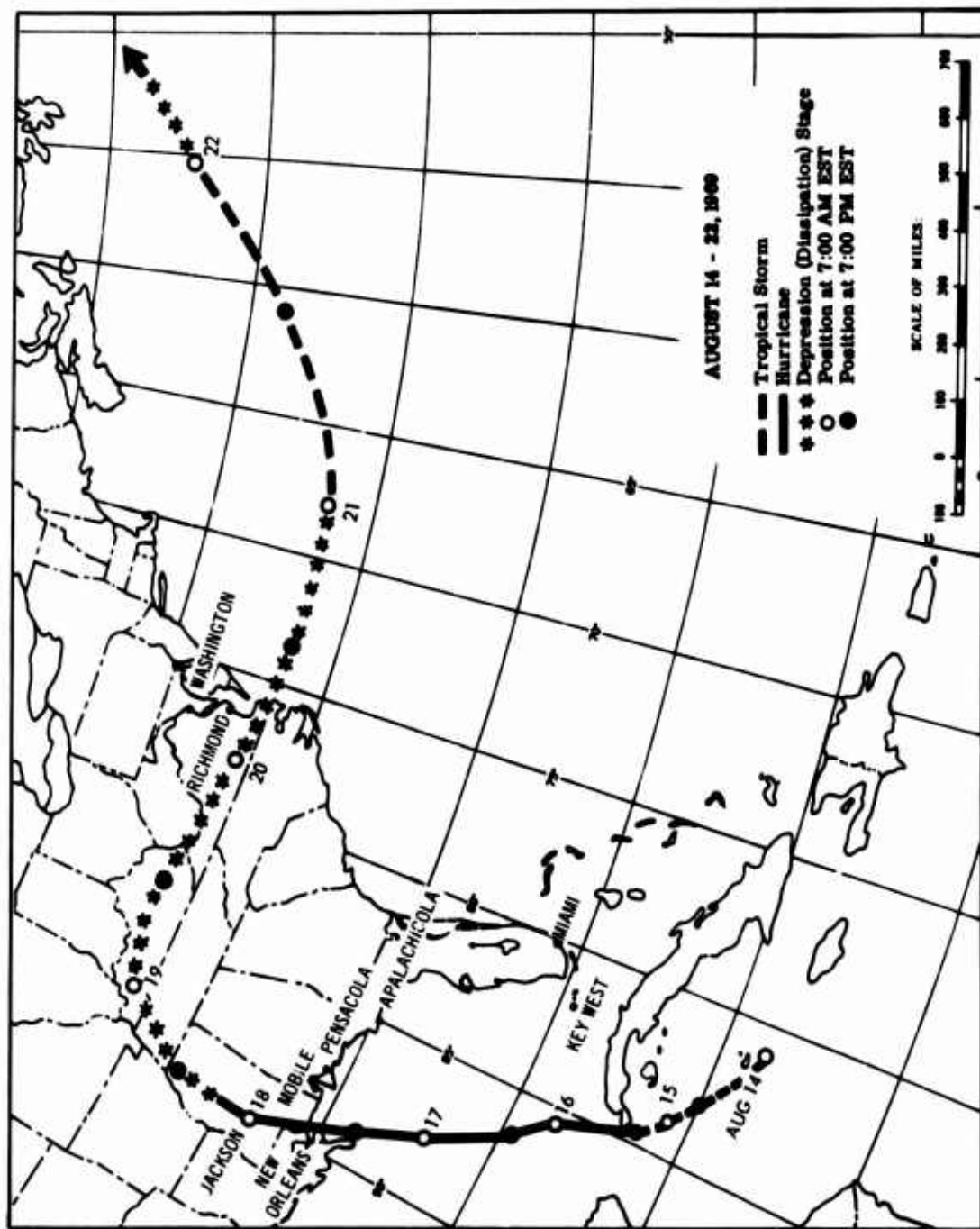


Figure 2.3 Path of Hurricane Camille.

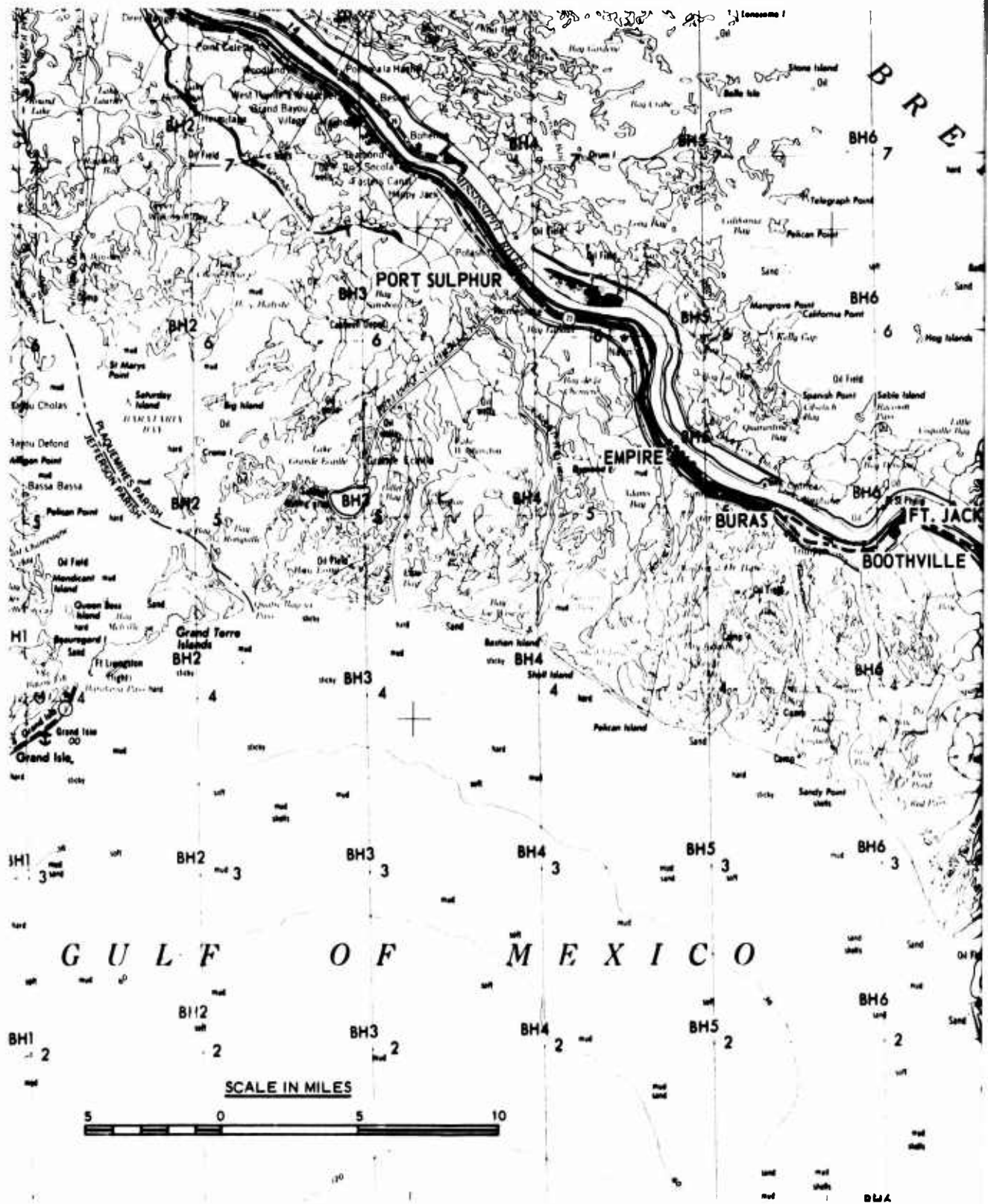
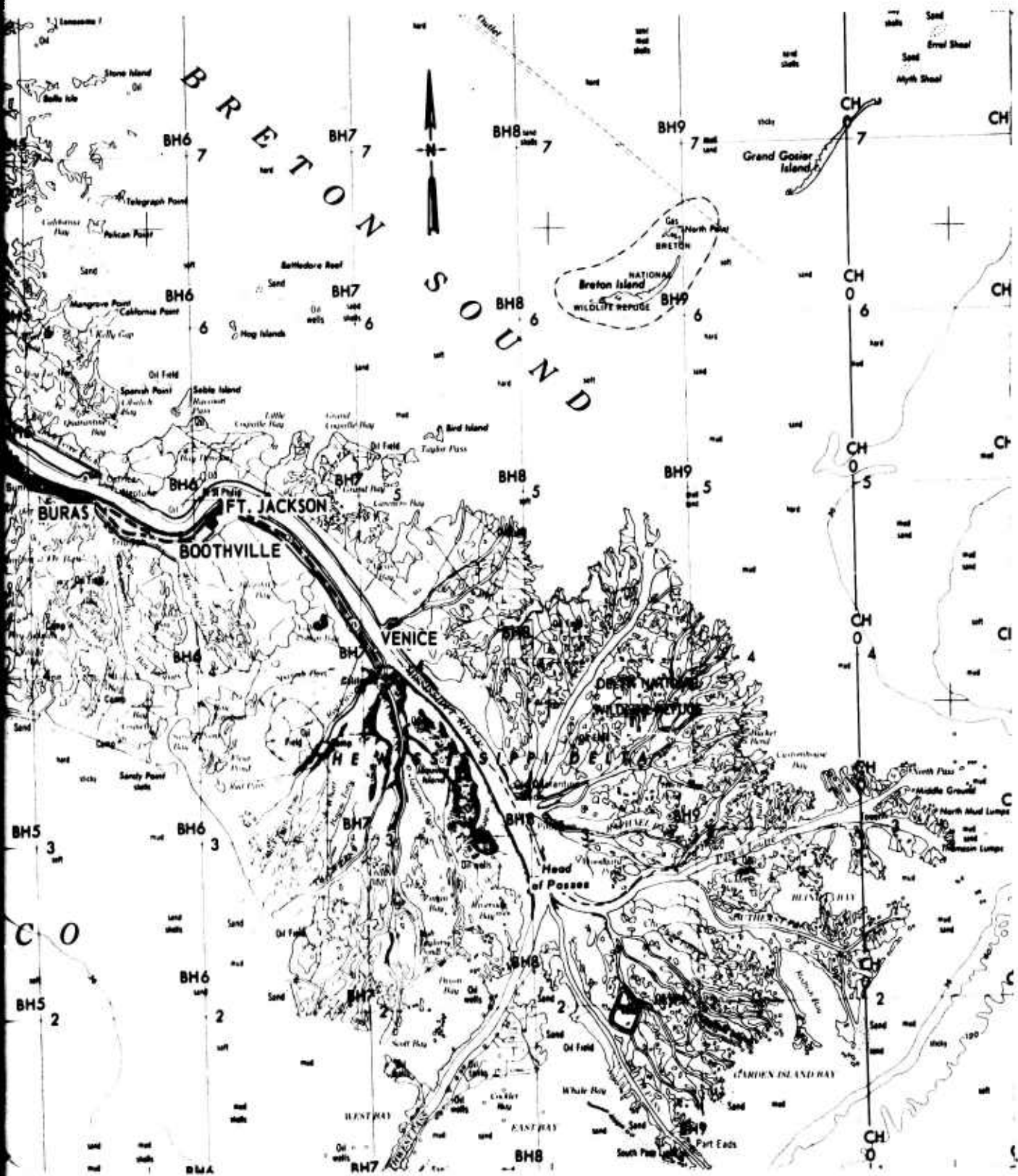


Figure 2.4 Lower Mississippi Riv



2.4 Lower Mississippi River delta area



Figure 2.5 Damage near Buras, Louisiana.



Figure 2.6 South side of Empire, Louisiana.



Figure 2.7 Between Empire and Buras, Louisiana.



Figure 2.8 Near Buras, Louisiana.



Figure 2.9 Buras area in Louisiana.

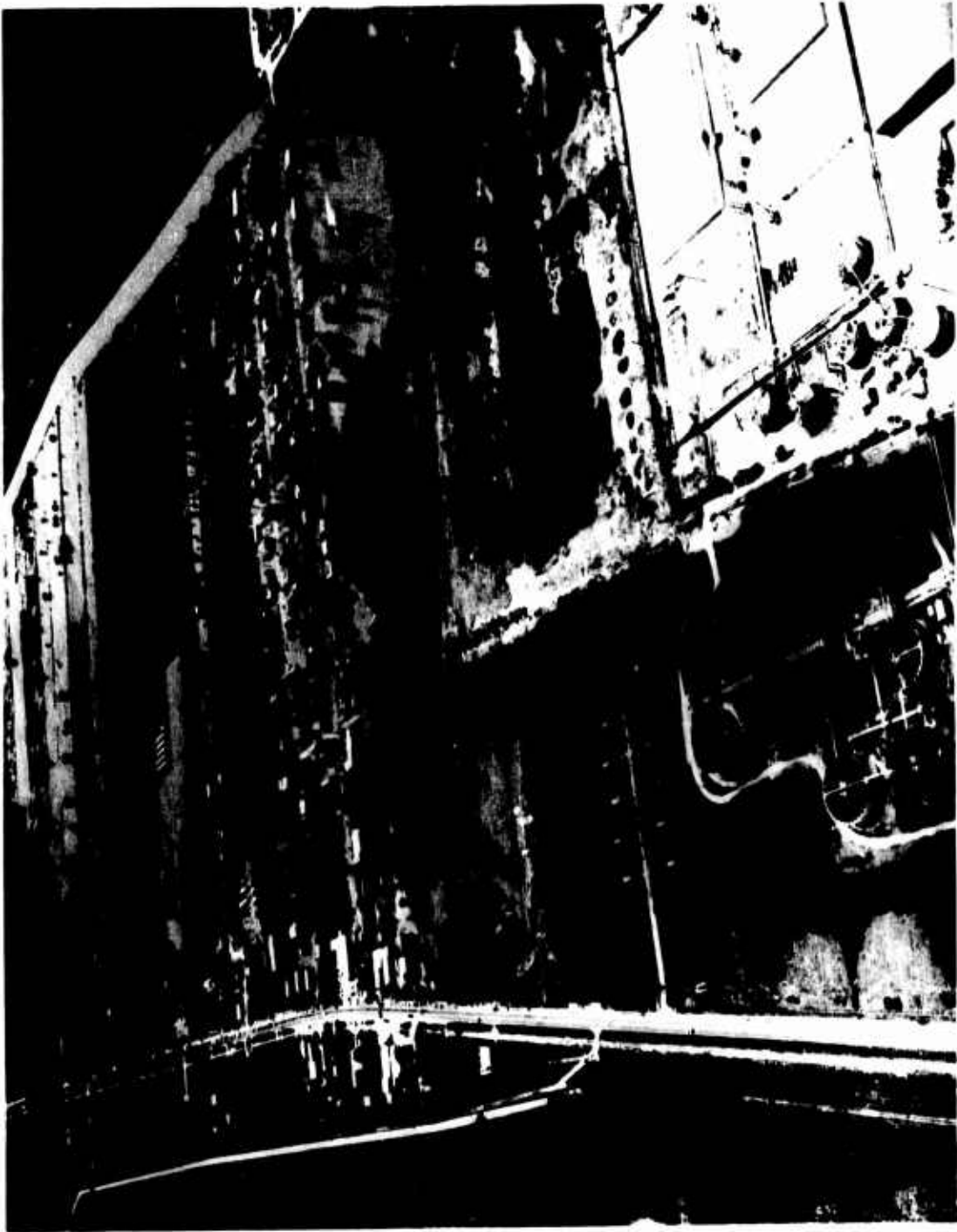


Figure 2.10 Home Place and Port Sulphur, Louisiana.



Figure 2.11 Back levee, near Buras, Louisiana.



Figure 2.12 Buras, Louisiana.



Figure 2.13 Below Buras, Louisiana.

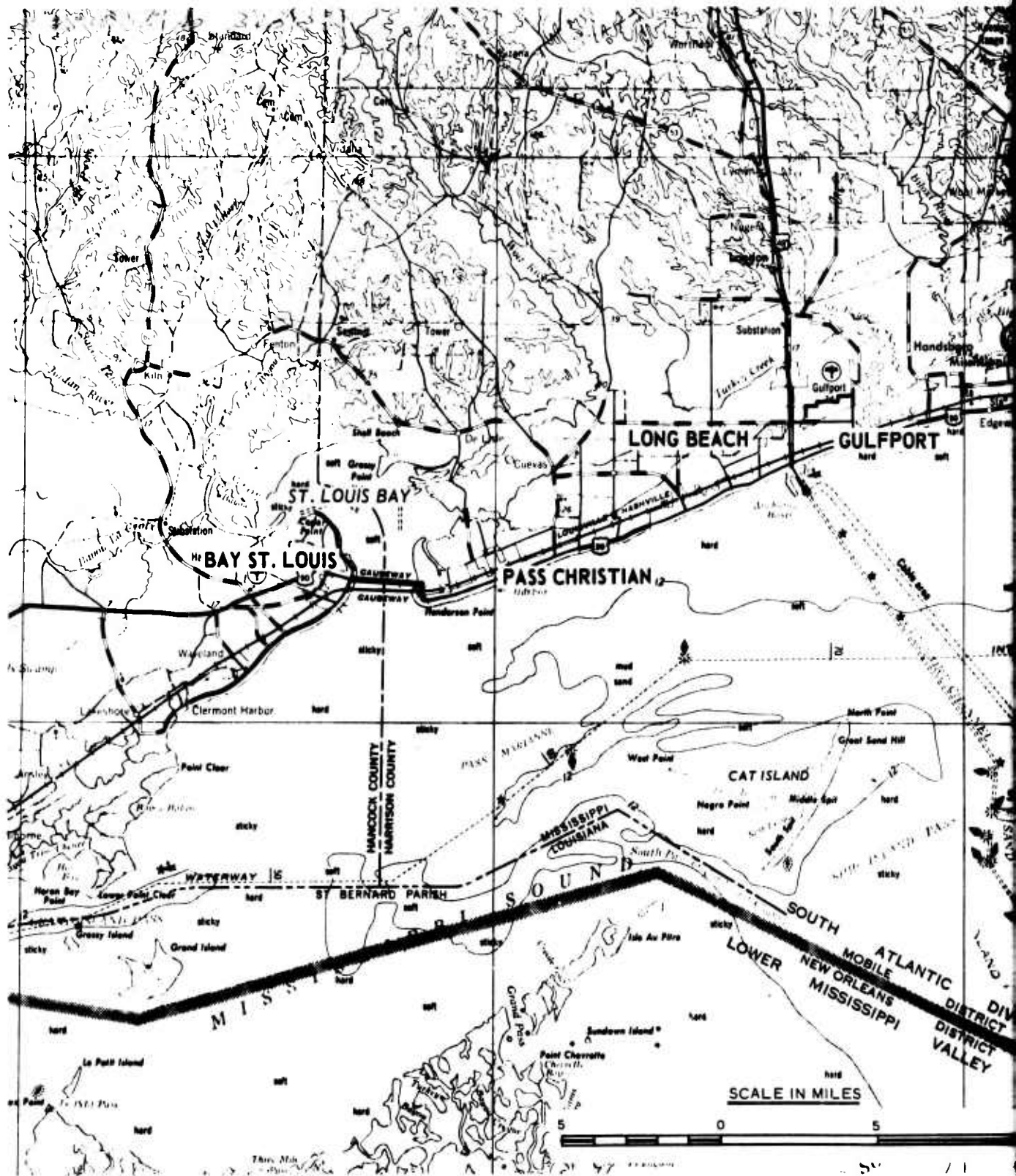


Figure 2.14 Mississippi Gulf Coast

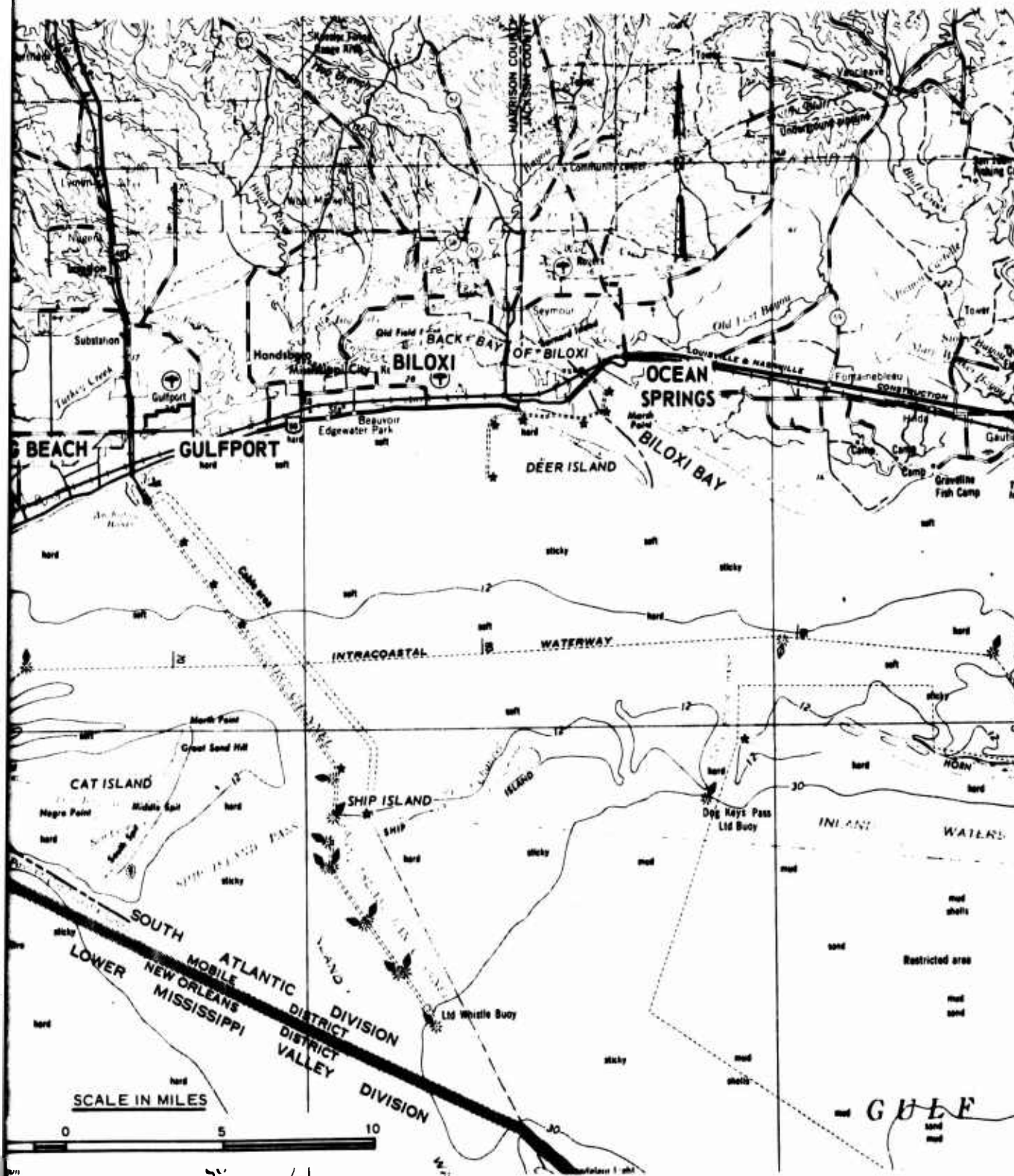


Figure 2.14 Mississippi Gulf Coast



Figure 2.15 Residential area in west Gulfport, Mississippi.



Figure 2.16 Residential district in west Gulfport, Mississippi.



Figure 2.17 Residences and debris line in west Gulfport, Mississippi.



Figure 2.18 Remains of motels and apartments, Long Beach area.



Figure 2.19 Gulf Plaza and apartments, east Pass Christian area



Figure 2.20 Motel building slab, between Pass Christian and Long Beach.



Figure 2.21 East end of Pass Christian downtown area.



Figure 2.22 Pass Christian, Mississippi.



Figure 2.23 Pass Christian, City Hall in foreground.



Figure 2.24 West Pass Christian, Mississippi.

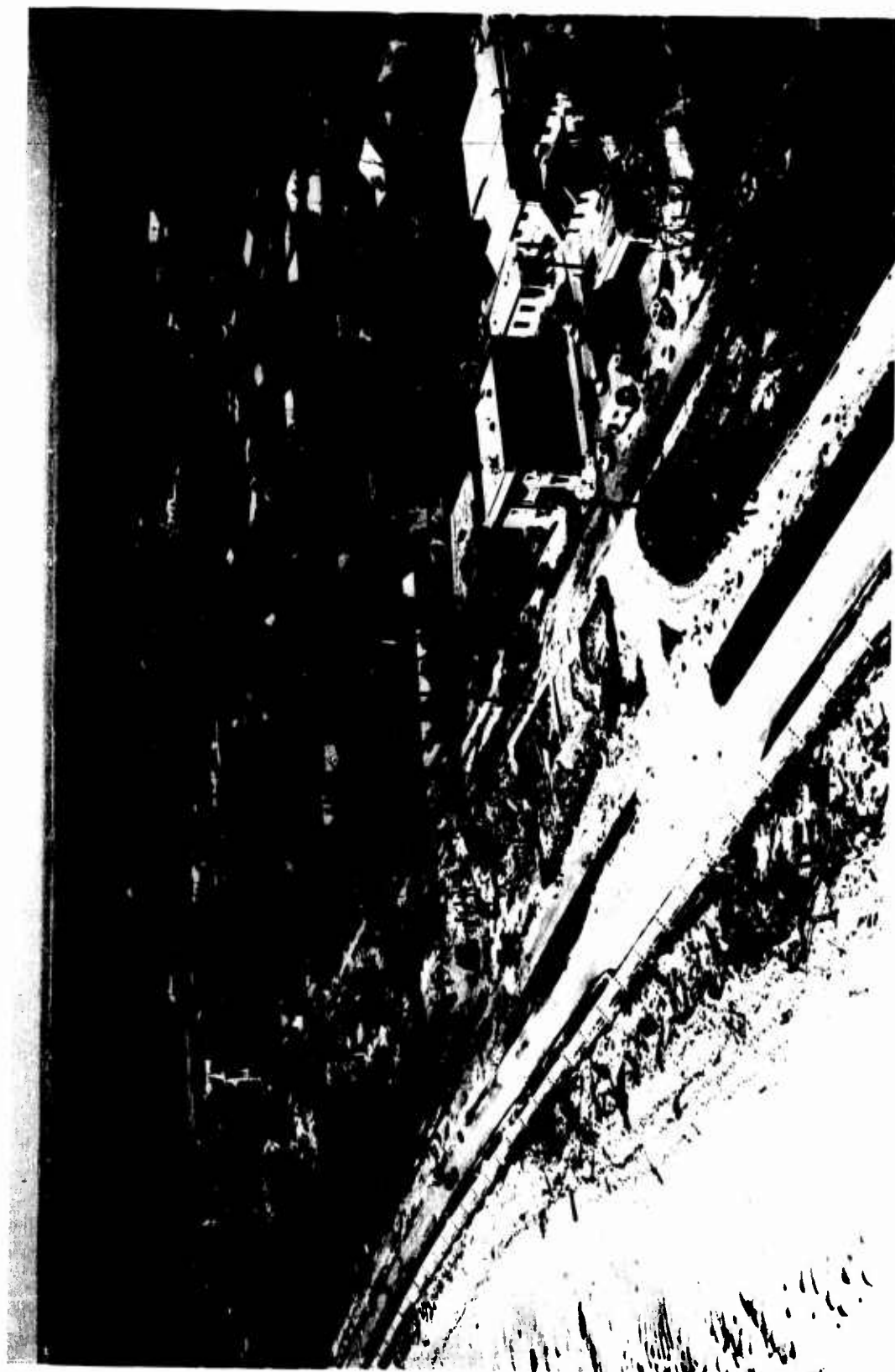


Figure 2.25 Pass Christian, Mississippi.



Figure 2.26 Henderson Point, on east shore of Saint Louis Bay, Mississippi.



Figure 2.27 Debris at east end of Bay Saint Louis Bridge, Mississippi.



Figure 2.28 Tug and paper rolls in debris, west Gulfport, Mississippi.



Figure 2.29 Debris from residences and Port facilities, west Gulfport, Mississippi.



NT17-30

Figure 2.30 Tank floated in from harbor, west Gulfport, Mississippi.

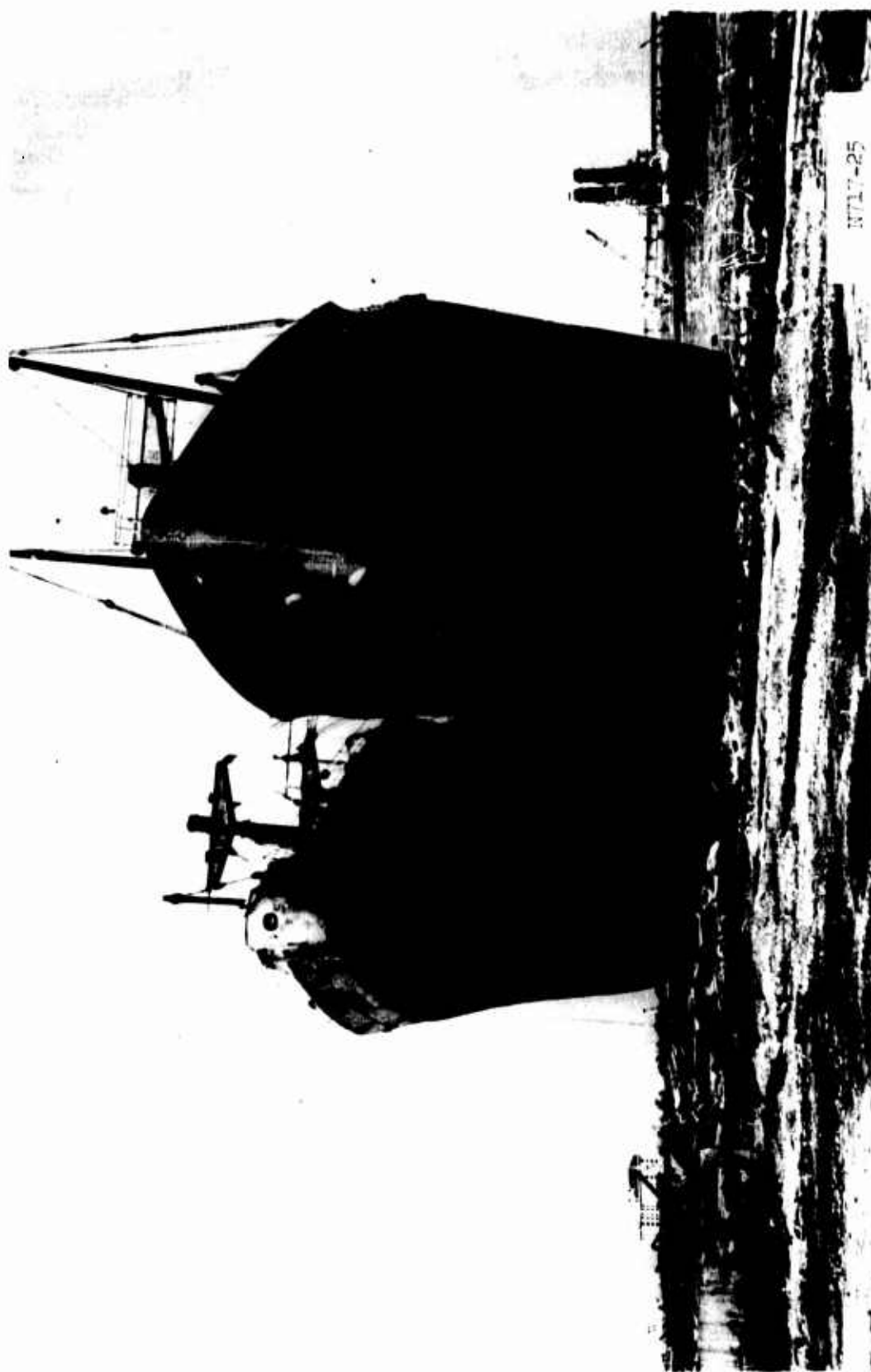


Figure 2.31 Ships aground, Fort of Gulfport.



Figure 2.32 Barge, debris, and damaged residence, west Gulfport, Mississippi.



N717-41

Figure 2.33 Debris of a shopping center, Long Beach, Mississippi.



Figure 2.34 Destroyed residence from front doo:steps, Long Beach, Mississippi.



Figure 2.35 Residence near Long Beach, Mississippi.

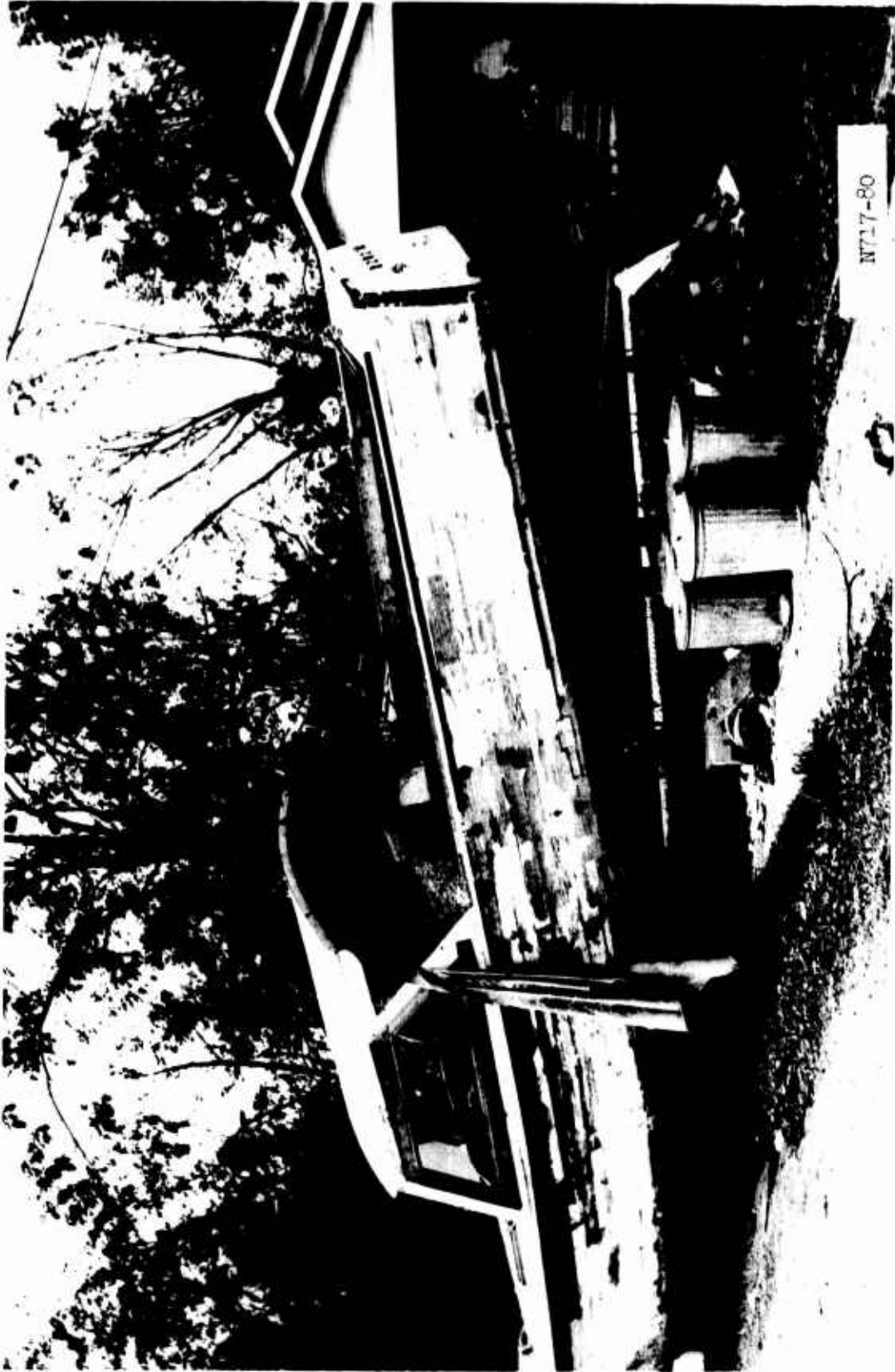


Figure 2.36 Boat ashore, east end of Biloxi, Mississippi.



Figure 2.37 Commercial building, Back Bay of Biloxi, Mississippi.



Figure 2.38 Water-damaged building, Back Bay of Biloxi.



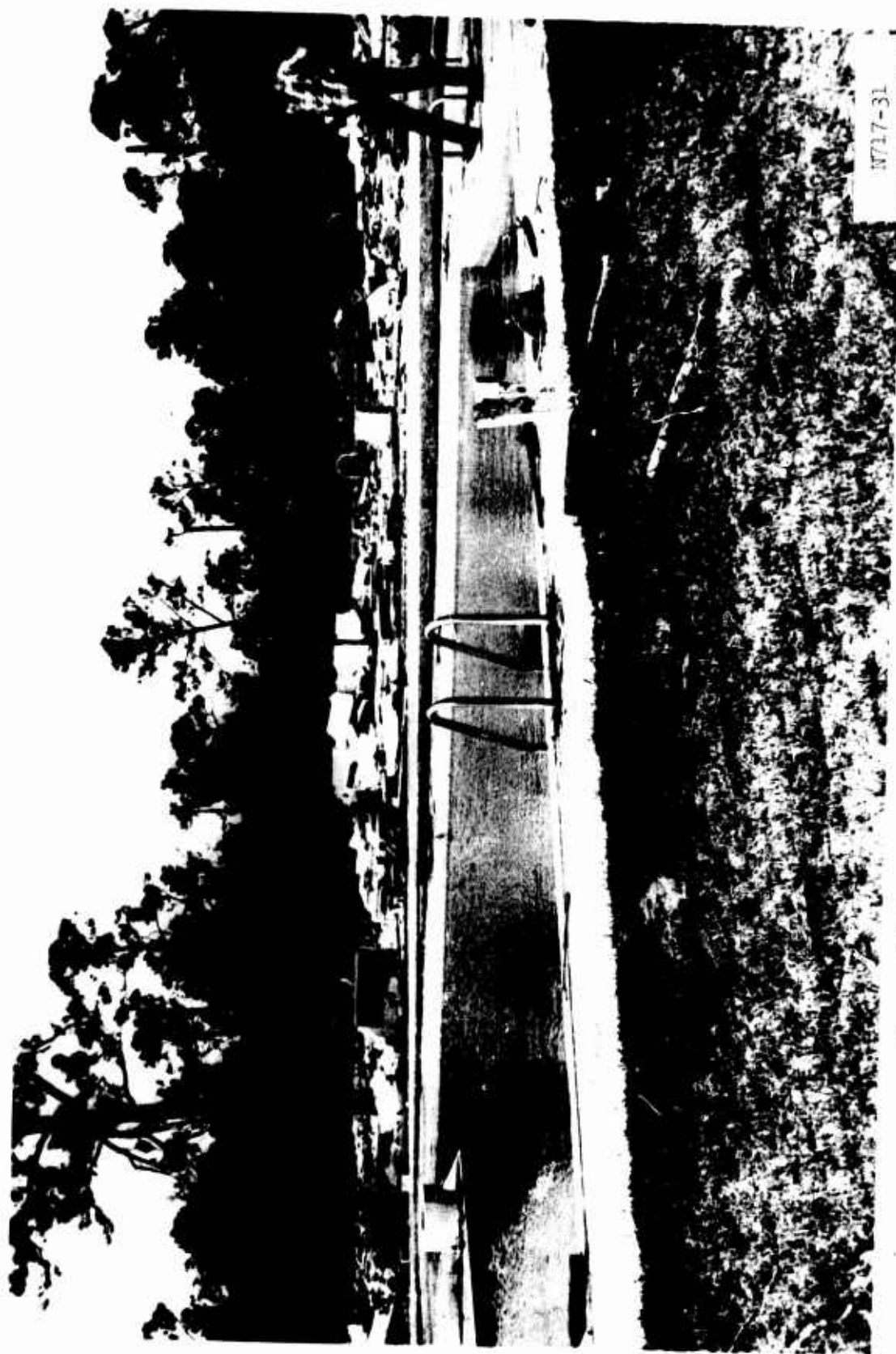
Figure 2.39 Oil storage tank floated inland, Back Bay of Biloxi.



Figure 2.40 Remains of brick and block residence, Long Beach area.



Figure 2.41 Motels, west of Biloxi, Mississippi.



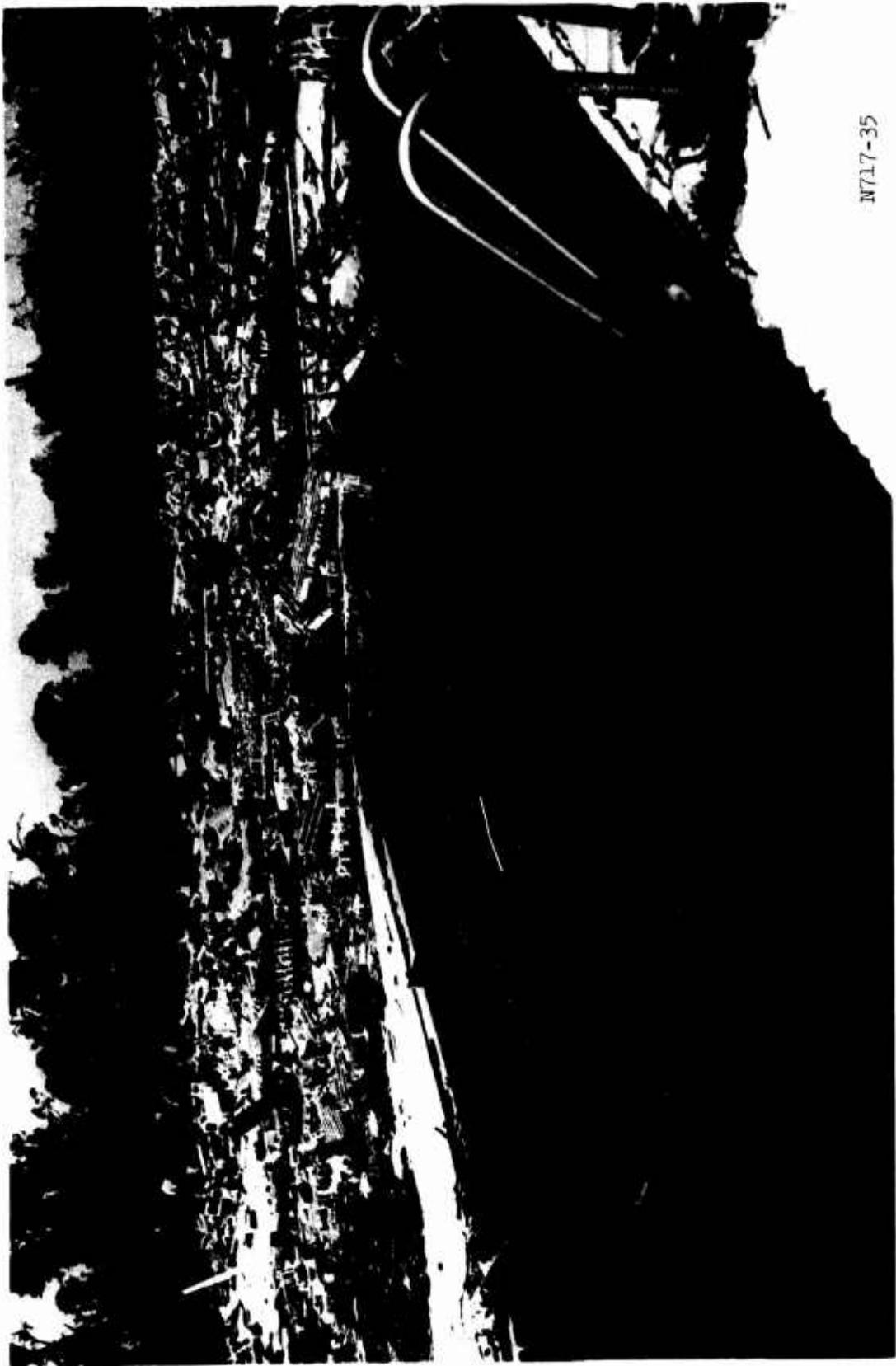
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Figure 2.42 Motel or apartment house, Long Beach area.



N717-56

Figure 2.43 Richelieu Apartments (23 dead), Pass Christian, Mississippi.



N717-35

Figure 2.44 Pool area, Gulf Villa Apartments, Long Beach area.



N717-33

Figure 2.45 Gulf Villa Apartments, Long Beach area.

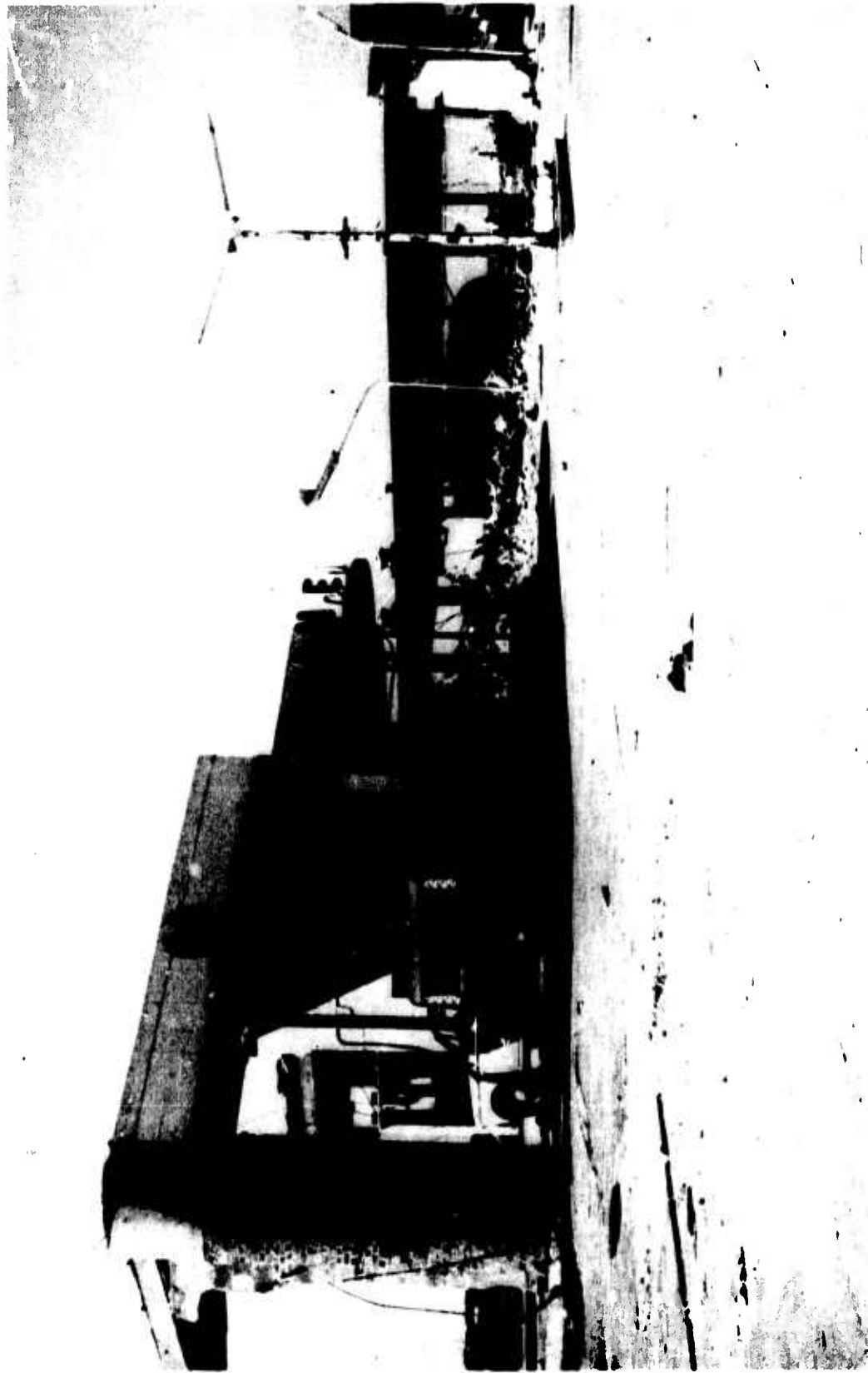


Figure 2.46 Service station, west Gulfport area.



Figure 2.47 Collapsed frame house, between Biloxi and Gulfport, Mississippi.



Figure 2.48 Collapsed frame house, Long Beach area.



Figure 2.49 Residence, Long Beach, Mississippi.



Figure 2.50 Steel frame recreation hall, Jones Memorial Park, Gulfport.



Figure 2.51 Frame restaurant structure, Biloxi, Mississippi.



N717-79

Figure 2.52 Frame motel structure, Biloxi, Mississippi. There had been fire damage before the storm to the building shown at the right.

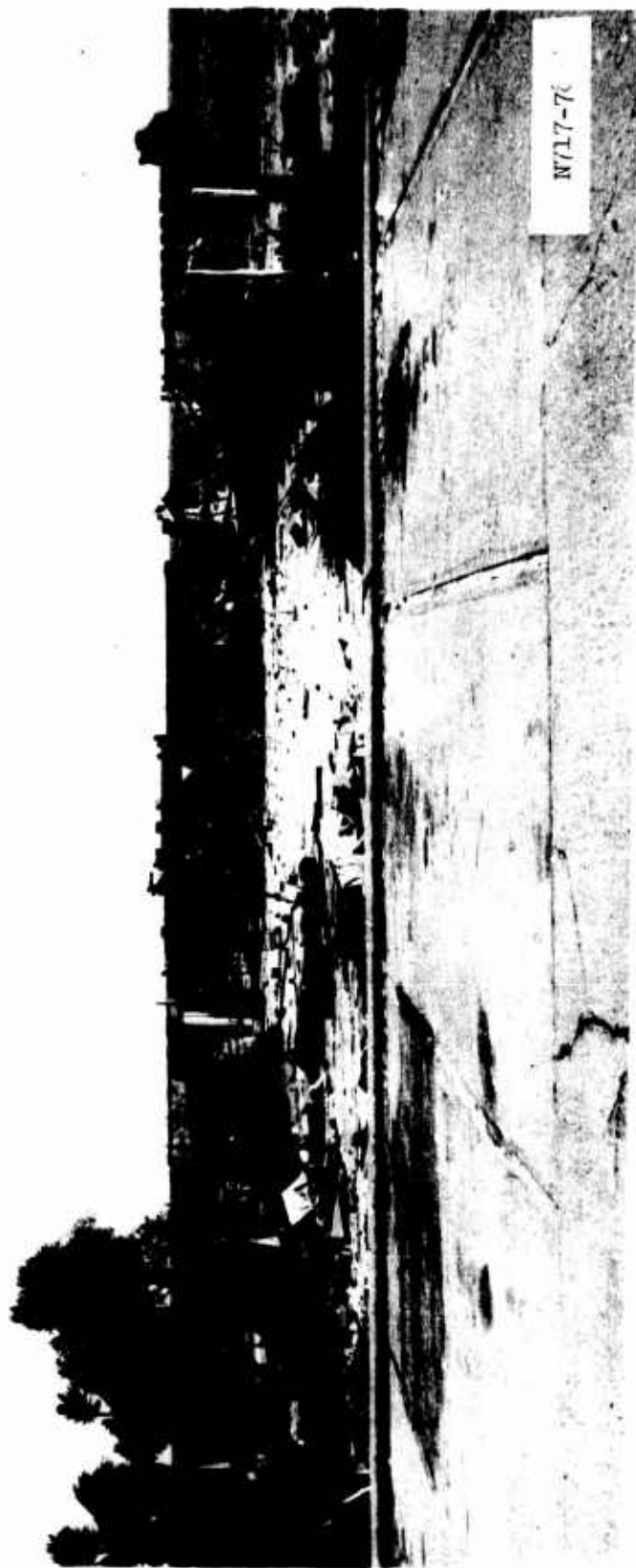


Figure 2.53 Concrete frame restaurant, Biloxi, Mississippi.

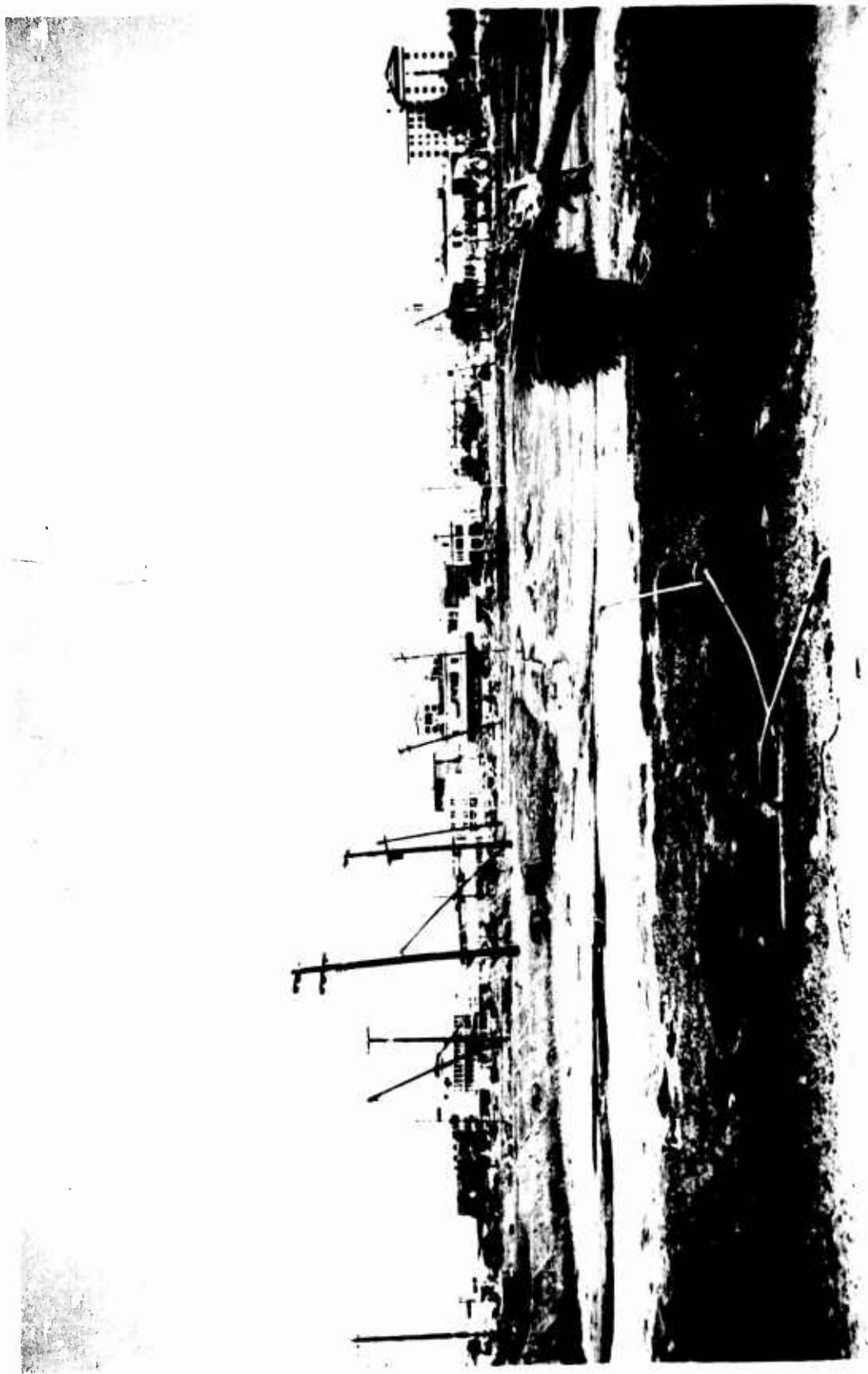


Figure 2.54 Gulfport business district from the south.



Figure 2.55 Poplarville High School, Poplarville, Mississippi.

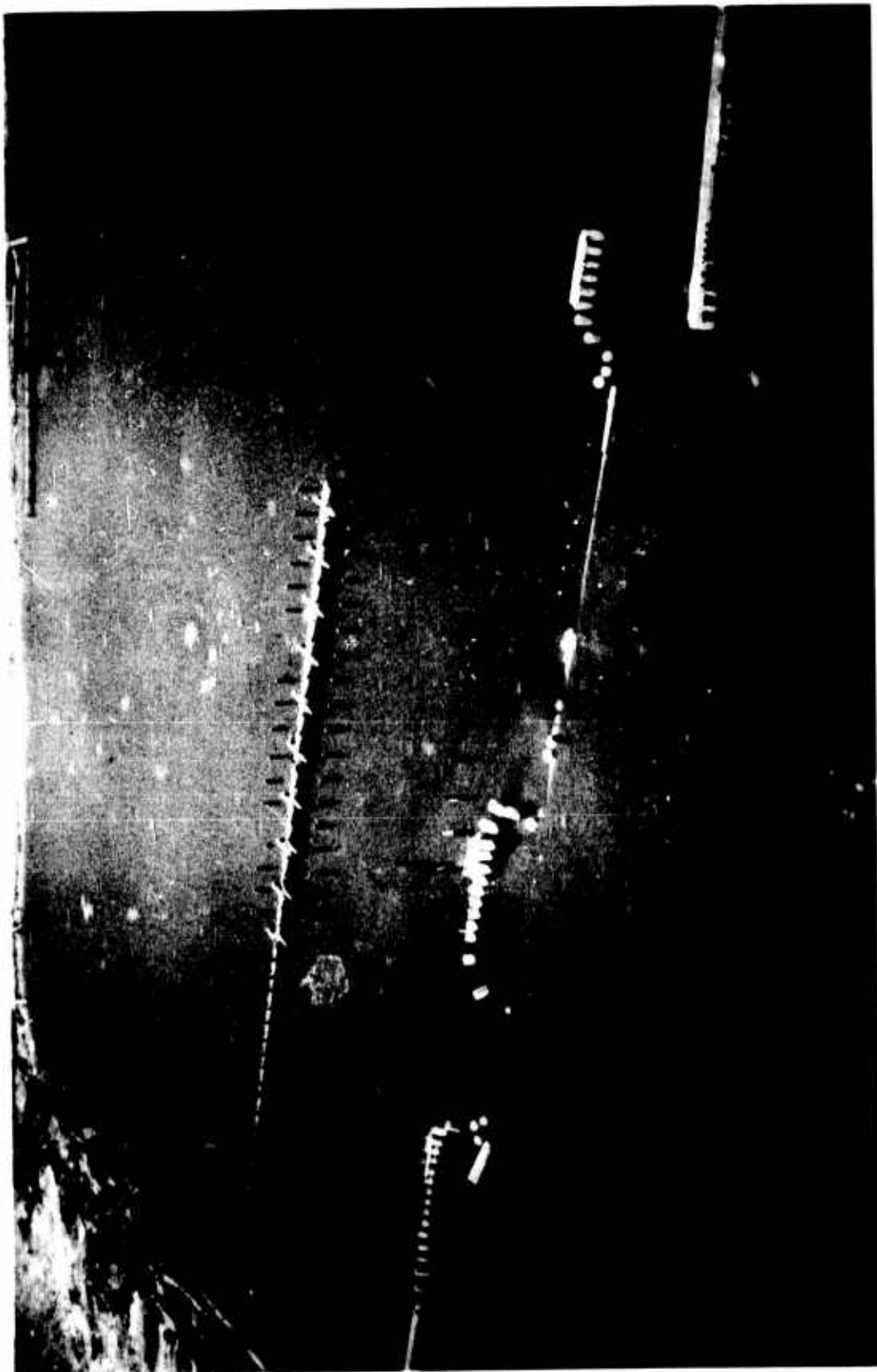


Figure 2.56 Pass Christian small-boat harbor, Pass Christian, Mississippi.

CHAPTER 3

CASE STUDIES OF STRUCTURAL DAMAGE

Several nonresidential structures were more closely examined and the damage to them will be reported in this Chapter in more detail.

Most structures chosen for more detailed study were significantly damaged but not totally collapsed. This excluded most masonry construction along the coast and other structures so totally destroyed as to make a meaningful examination difficult or impossible and most larger buildings inland where any damage was usually minor and probably hidden by nonstructural elements of the building.

3.1 STATE DOCK

This building is a large clear span (span of about 125 feet) warehouse located at the southern tip of the Port of Gulfport. It is of rigid-frame construction with combination columns (steel sections encased in structural concrete) and with tilt-up concrete wall panels about 20 feet square by 6 inches thick and roll-up doors forming the walls. Light sheet metal purlins run along the length of the building and support a sheet metal roof. The columns appeared to have been cast in two steps, one to encase the steel section and the second to key in the tilt-up walls. The general construction is shown in Figures 3.1 and 3.2.

As shown in Figures 3.3 through 3.5, the end facing south-southeast and the first bent collapsed into the building with the tilt-up panels of this end wall falling with the columns. The tilt-up panels along the east side of the building were pushed into the structure, and those along the west side fell away from the structure. Like many other structures along the coast, this building was subjected to loadings far above those probably anticipated in their design.

The connections at the base of the columns along the collapsed end wall failed. The dowels at the corner columns, shown in Figures 3.6 and 3.7, were very short, of small size, and had pulled out without breaking. The dowels in other columns along the end wall were larger and longer but still not adequate to develop the tensile strength of the dowel (Figure 3.8).

Dowels in at least one column were placed outside of the reinforcing cage and were able to break out of the column without even bending (Figure 3.9). Cold joints were found at the base of some columns. Only one broken reinforcing bar was seen at the column bases along the collapsed end wall.

The end wall probably received only small lateral support along its top from the small roof purlins and effectively functioned as a large slab simply supported at both ends and along the bottom. This structure could not resist the extremely large lateral loadings from the storm, probably failed first near the top center, and fell into the building.

One large (No. 9 or 10) bar contained on the horizontal beam over the tilt-up panels of the end wall ruptured with little ductility being displayed at the location of a bend (Figure 3.10).

The Port buildings contain 30,000 low protection factor (a PF of less than 40) NFSS shelter spaces. The number assigned to the State Dock, if any, was not determined.

Other Port buildings were either metal-clad rigid-frame buildings, which lost almost all of the sheeting on the walls, or older reinforced concrete rigid-frame buildings located on the leeward side of the Port and which suffered only minor structural damage, even though much of their contents were washed out. Some of the metal-clad buildings are visible in Figure 3.11 and in the background of Figures 3.13 and 3.17.

3.2 MARINE LIFE AQUARIUM

Marine Life consisted of a group of various structures (Figure 3.12). A large steel arch which this team was told was designed for 120-mph winds sheltered a display tank and a concrete seating area. A small (30 to 50 spaces) NFSS shelter was located under this seating area. A concrete floor and block wall structure surrounded the large display tank to the east of the arch.

The steel arch remained standing despite the loss of two pipe column supports at the northeast corner (corner nearest the camera and to the left in Figure 3.13) and the dropping of the other three columns on the east side. Some roofing was torn off the west side of the arch (Figure 3.14). The middle pier supporting the west end of the arch was badly damaged

(Figure 3.15) and no doubt would have functioned better had more column ties been included near the top of the pier.

The approximate maximum water wave level during Hurricane Camille is the top of the bent cladding on the arch (see Figure 3.16).

The block wall along the west side of the arch was almost completely destroyed (Figure 3.17).

The seating over the NFSS area rested directly upon five concrete block walls (mostly unfilled and containing small amounts of block ties) and consisted of 8- by 10-inch beams forming the front of the steps with a thin slab reinforced with welded-wire fabric for the tread portion. The beams contained four No. 6 bars, one on each corner, and stirrups on about 18-inch centers. The bars were lapped 6 inches or more over the block walls.

This seating area under the east side of the arch was completely collapsed (Figures 3.18 and 3.19). The seating area appeared to have failed when the water lifted the seating and dropped it onto the walls crushing some block and failing the beams of the seating portion at the supporting walls, thus transforming the beams into essentially simply supported spans which then fell (Figures 3.20 through 3.22). It was not clear whether these beams had been designed for continuity; the steel arrangement, but not the splice length, suggests that they were.

The welded-wire fabric of the seating slab tore out of the beams easily and had little or no cover, as can be seen in the beam shown in the foreground of Figure 3.20 and in Figure 3.23, which shows a beam that ultimately failed in torsion.

The structure around the large tank was in ruins (Figure 3.24). Several cases of extreme corrosion of the reinforcement were seen. Two examples of such corrosion can be seen in Figures 3.25 and 3.26; this corrosion is somewhat surprising since both the beam and the slab shown had 1-1/2 inches of cover. Although the tanks contained water, conditions at these beams and slabs should not have been more severe than those for many coastal structures.

A bundle of No. 6 bars was found by the arch, raising the question of whether it was extra or had been left out of something somewhere.

An 8-foot-high block wall immediately north of the arch had been pushed over intact (Figure 3.27). This wall had been tied down with one No. 6 bar at 12-foot centers.

3.3 MARINE SHOP

A small marine retail store and shop located in a steel-frame building directly south of Marine Life was totally destroyed. This building, consisting of four 12-foot-wide bays of 36-foot span, was directly in the path of numerous small boats (up to 50 feet) which broke from their moorings and moved through the area.

The steel frame ended up in a pile west-northwest of the building slab (Figure 3.28) with one column still tied to the slab (Figure 3.29). The welds at the base plate of another column failed (Figure 3.30).

The weld between the flange and web of a 12-inch fabricated plate girder failed, as shown in Figure 3.31. This was a consequence, not a cause, of failure.

3.4 PASS CHRISTIAN CITY HALL

This building, shown in Figure 3.32, is a two-and-one-half-story building with a heavy wooden frame (2-inch dimension lumber on close spacing) and a brick exterior, located in the heart of Pass Christian. After Camille, it was the only building remaining on the south side of Pass Christian's main street for more than two blocks in either direction. Most other buildings in the area appeared to be light, long span, wooden commercial buildings typical of many older and small town business districts (Figures 3.33 through 3.35).

The City Hall appeared to have suffered little, if any, structural damage. The building had swayed enough during the storm to crack plaster (Figure 3.36), some windows were broken, and water was at least 5 feet deep in the first floor above the basement.

An OCD Emergency Operating Center (EOC) was located in the basement on the seaward side of the building. The poststorm condition of this room is shown in Figure 3.37.

3.5 RAMADA INN

The inspection team was told that this motel complex in Long Beach was designed to be hurricaneproof. It actually performed quite well compared to the structures around it.

The main building (Figure 3.38) was parallel to the highway. There appeared to be two wings perpendicular to and behind the main building. The east wing was completely leveled and the west wing was relatively undamaged. The east wall of the main building was out (Figure 3.39), and the entire first floor suffered extensive water damage, especially in the dining area (Figure 3.40).

3.6 A&P AND ADJOINING SHOPPING COMPLEX

This complex, located several blocks east of the Ramada Inn in Long Beach, was constructed mainly of block walls, steel pipe columns and main beams, and with small angle trusses or bar joists supporting the roof. The front of the A&P store is shown in Figure 3.41.

A Walgreen's store located on the seaward side of the A&P collapsed completely with much debris ending up in or behind the A&P (Figure 3.42). The angle trusses appeared to have been set into the block and brick exterior walls and fell with the wall. Small bulb angles placed atop the trusses and supporting the roofing panels spaced the trusses laterally.

The two side bays of the A&P store collapsed, probably when the walls between this building and the adjoining stores were destroyed. One corner of the wooden truss hip roof at the front of the A&P was left cantilevered over the debris (Figure 3.43). The center bay, supported on steel beams at both ends, did not suffer extensive structural damage (Figure 3.44). The presence of lamps in the fixtures shows that the water did not reach the ceiling level.

The center row of beams and columns of the Morgan and Lindsey variety store directly north of the A&P survived with most of the roof trusses remaining connected to the beams (Figure 3.45). The other ends sat on masonry walls which collapsed.

In this complex of stores, two pipe columns in which bolt holes

did not line up with those in the beams above had simply been tack welded, which indicates that some of the workmanship was questionable. Most of the 24-inch-deep trusses were connected to the beams with small welds about 2 inches long.

3.7 GULF PLAZA

Several stores, including a large discount-type store, were located in Gulf Plaza near the Long Beach-Pass Christian boundary and contained in a large pipe column, beam, and bar joist structure with glass and block walls. As can be seen in Figures 3.46 and 3.47, the exterior walls and store contents were completely washed away, leaving only portions of the building frame. It appeared that only a minimum amount of welding had been used to attach the bar joists to the supporting beams.

An apartment complex located east of the shopping area was completely leveled, with most of the floor slab cleared of debris by the storm (Figure 2.19).

3.8 BROADWATER BEACH BOAT MARINA

This sizable small-boat marina, located near the west end of Biloxi, consisted of cast-in-place concrete columns and precast arches (double T sections attached to large concrete "bow" sections). This structure was specifically designed for heavy hurricane loading and therefore is not a typical structure.

The connections and details of the marina appeared to be very well designed and constructed. Some columns showed a flexural failure near the base with no hint of connection failure. The welds joining the anchor plates of the precast elements appeared to be generally as strong as the elements themselves.

Some of the double T sections were damaged when the arches rocked back and forth (Figure 3.48) with differential motion occurring at the valley where two arches met.

The two north corners of the marina were destroyed (Figures 3.49 and 3.50), very possibly by boats coming through these parts of the marina.

The presence of a large sailboat high above the water and against the

office area (Figure 3.51) indicates a lower bound on the water height in this area.

3.9 BAY SAINT LOUIS BRIDGE

This four-lane multispans causeway crosses from Pass Christian to Bay Saint Louis. Precast deck slabs, two lanes wide and supported on pile bents, form the bridge.

The water appeared to have lifted the seaward deck slabs up enough for the rocker bearings on the east end of each span to fall out, resulting in a sawtooth appearance along the south side of the bridge (Figures 3.52 and 3.53). Some of the railing sections were tilted inland, and all but one lamp was torn from its pole. One span was moved about 4 feet laterally (Figure 3.54). Considerable concrete was spalled along the bridge centerline where the two deck slabs joined. The west abutment was heavily damaged by wave action (Figure 3.55).

More extensive damage was reported for a similar bridge east of Biloxi; this bridge was not visited by the survey team.



Figure 3.1 Close-up view of general construction of State Dock.



Figure 3.2 General view of State Dock.



Figure 3.3 Collapsed end wall of State Dock.



N717-74

Figure 3.4 Close-up view of collapsed end wall of State Dock.



..17-75

Figure 3.5 Failure of tilt-up walls along west side of State Dock.



Figure 3.6 Southeast corner column, State Dock.



N717-76

Figure 3.7 Southwest corner column, State Dock.



Figure 3.8 End-wall column and panel, State Dock.



Figure 3.8 End-wall column and panel, State Dock.



Figure 3.10 Ruptured bar on spandrel beam, State Dock.

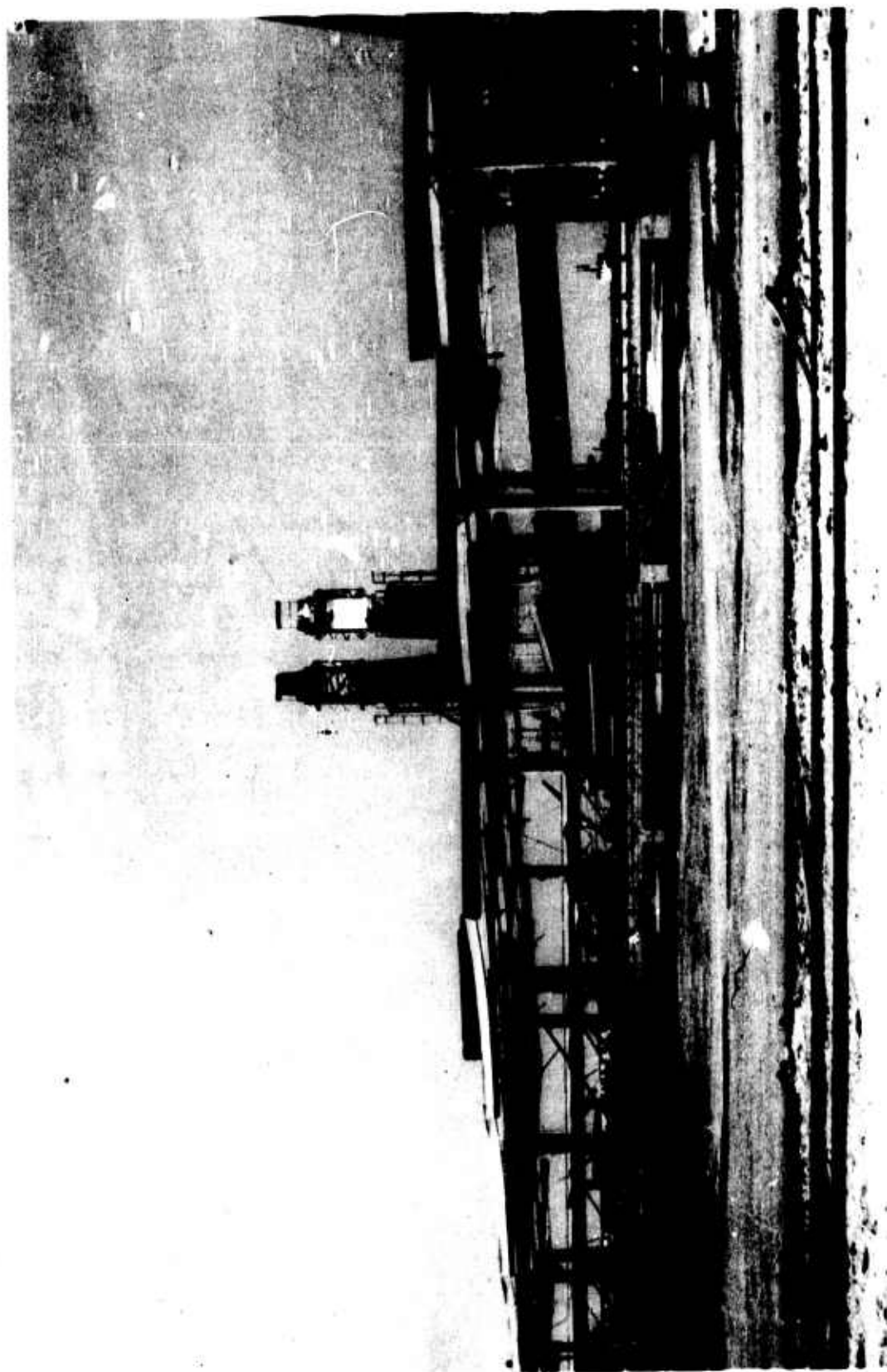


Figure 3.11 Buildings on east side of Port of Gulfport, Mississippi.



Figure 3.12 Marine Life Aquarium.



N.17-16

Figure 3.13 Marine Life steel arch.



N717-17

Figure 3.14 Marine Life arch.



Figure 3.15 Center pier supporting west end of arch, Marine Life.



N717-4

Figure 3.16 Southeast corner of Marine Life arch.



Figure 3.17 West end of Marine Life arch.



N717-5

Figure 3.18 Seating area under Marine Life arch.



N717-20

Figure 3.19 Seating area and arch at Marine Life.



Figure 3.20 Close-up of seating area, Marine Life.



N717-12

Figure 3.21 Overhead view of beam failure over block wall, Marine Life.

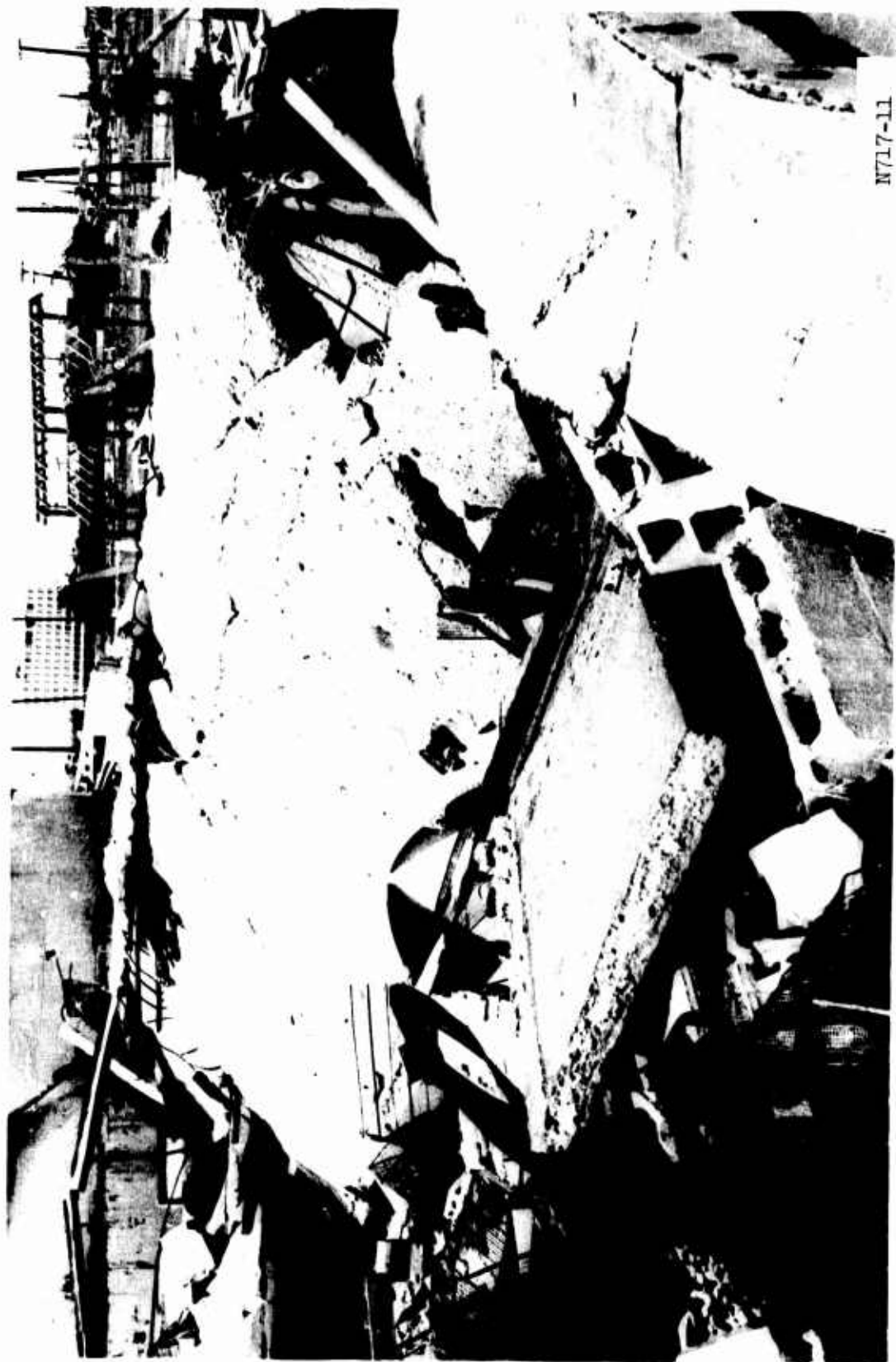


N717-13

Figure 3.22 Side view of beam failure over block wall, Marine Life.



Figure 3.23 Beam failed in torsion, seating area of Marine Life.



N717-11

Figure 3.24 Structure around large tank, Marine Life.



Figure 3.25 Reinforcement corrosion in a beam, Marine Life.



Figure 3.26 Reinforcement corrosion in a slab, Marine Life.



Figure 3.27 Block wall north of Marine Life arch.



Figure 3.28 Steel frame of Marine Shop south of Marine Life.



Figure 3.29 Base of column at Marine Shop.



Figure 3.30 Base plate for steel column, Marine Shop.



Figure 3.31 Weld failure of a plate girder, Marine Shop.

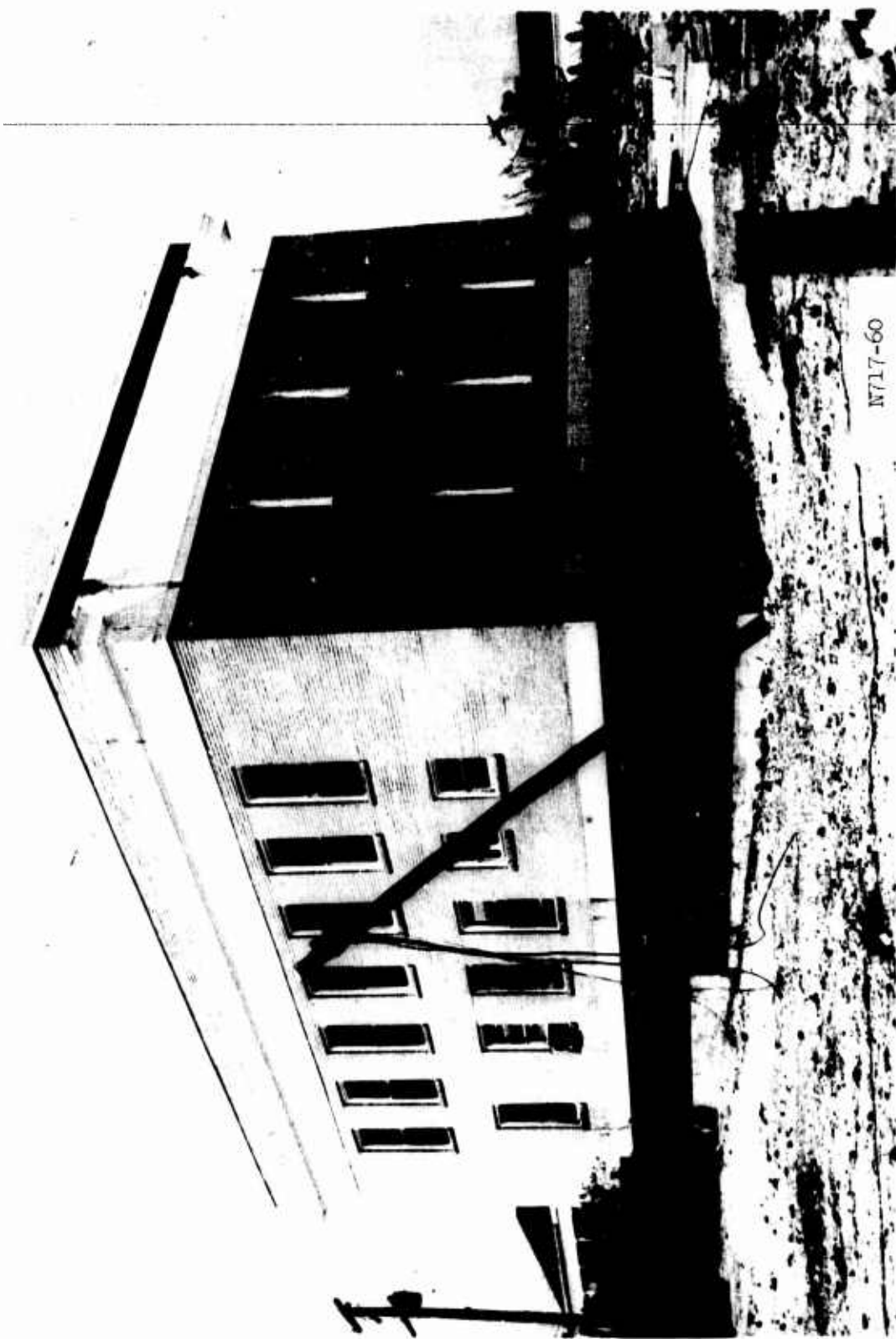


Figure 3.32 Pass Christian City Hall.



Figure 3.33 Businesses behind and east of Pass Christian City Hall.



Figure 3.34 Area east of Pass Christian City Hall.

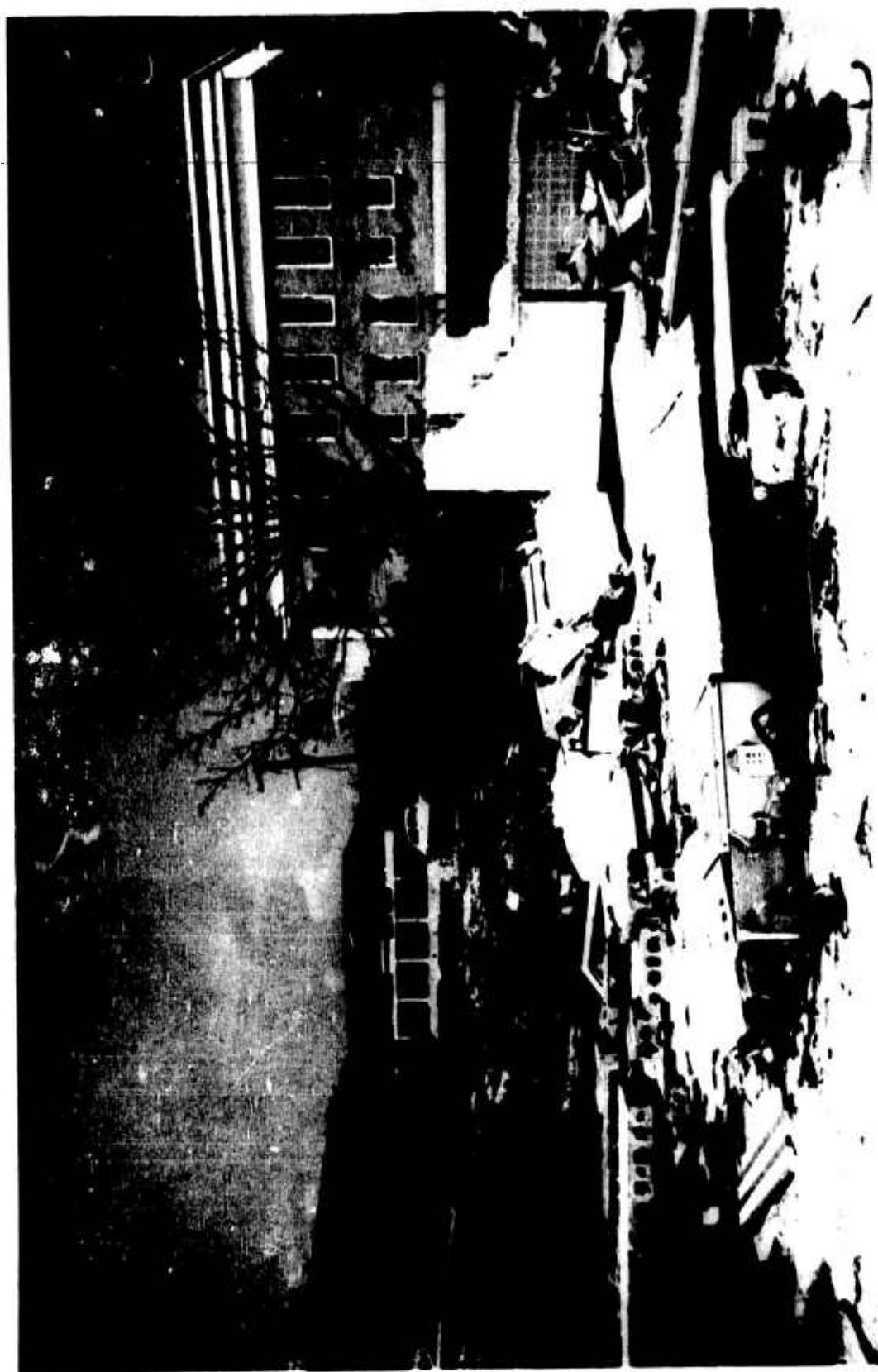


Figure 3.35 Area west of Pass Christian City Hall.



Figure 3.36 Wall damage, Pass Christian City Hall.



N717-59

Figure 3.37 Emergency Operating Center, Pass Christian City Hall.



Figure 3.38 Ramada Inn, Long Beach.



Figure 3.39 East wall of Ramada Inn main building.



Figure 3.40 Ramada Inn dining area.



Figure 3.41 Front of A&P store, Long Beach.



Figure 3.42 Side view of A&P with remains of Walgreen's in foreground, Long Beach.



Figure 3.43 Debris in A&P and Walgreen's stores.



Figure 3.44 Central bay of A&P, Long Beach.



Figure 3.45 Morgan & Lindsey store, Long Beach.



Figure 3.46 Gulf Plaza shopping center.



Figure 3.47 Interior of Gulf Plaza shopping center.



N717-23

Figure 3.48 Broadwater Beach marina.



Figure 3.49 Northeast corner of Broadwater Beach marina, looking north.



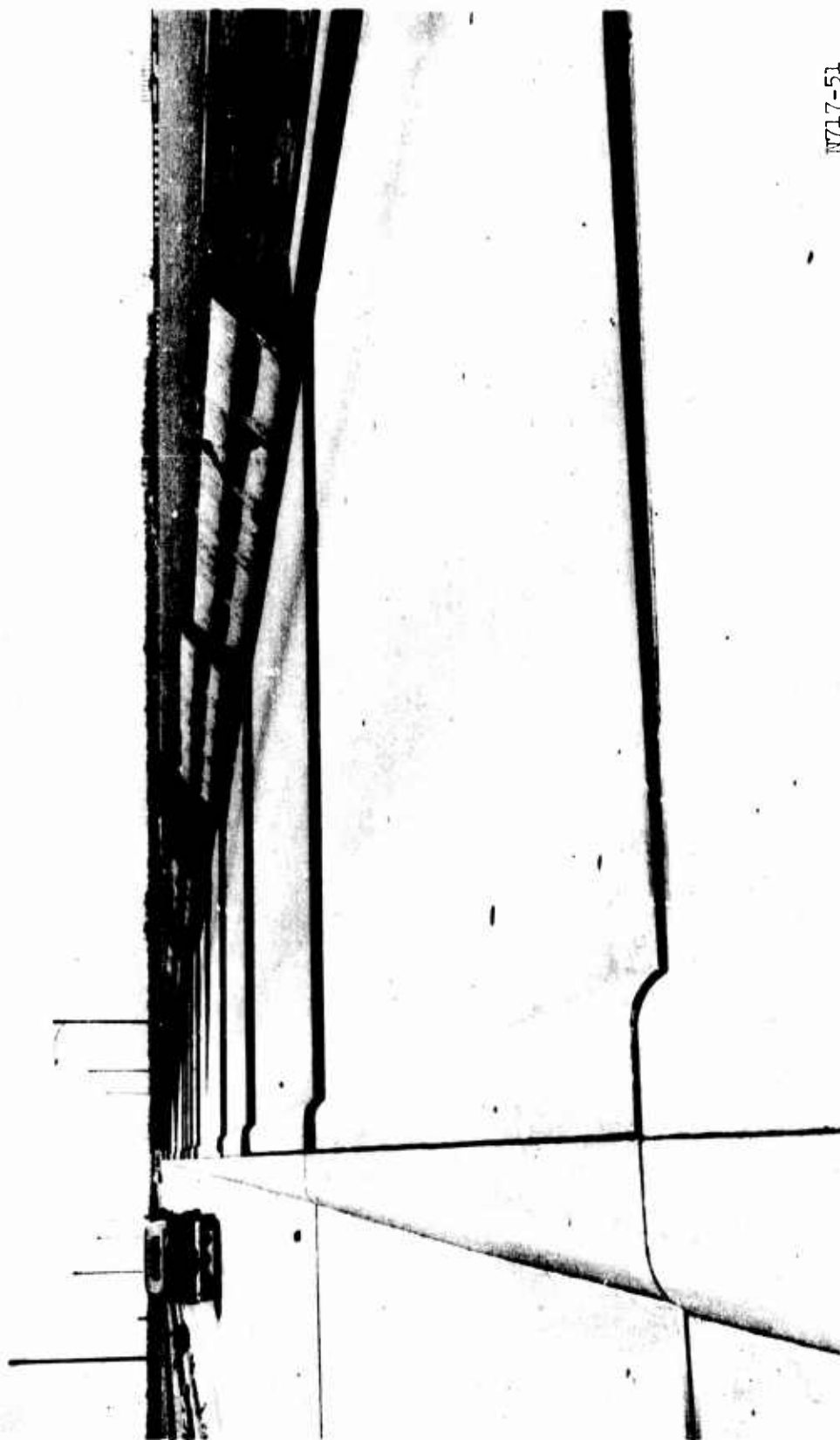
Figure 3.50 Northeast corner of Broadwater Beach marina, looking west.



Figure 3.51 Sailboat on Edgewater Beach marina office area.



Figure 3.52 Bay Saint Louis Bridge, looking east.



W717-51

Figure 3.53 Deck of Bay Saint Louis Bridge, looking east.



Figure 3.54 Displaced span of Bay Saint Louis Bridge.



N717-49

Figure 3.55 West abutment of Bay Saint Louis Bridge.

CHAPTER 4

DAMAGE TO COMMUNICATIONS, UTILITIES, AND AGRICULTURE

4.1 HIGHWAYS

Almost all of the highways were initially impassable because of large amounts of debris, sand, and fallen trees. Considerable amounts of sand were washed over parts of U. S. 90 along the coast.

Highway 90 along the west side of Bay Saint Louis was seriously undercut by wave erosion and washed away in places (Figure 4.1) even though the highway was at an estimated elevation of 20 feet.

The seaward two lanes (east-bound lanes) of U. S. 90 along the coast were heavily damaged by water erosion, especially in the Pass Christian and Long Beach areas. Much of the soil between the seawall and the highway washed out, causing portions of the highway to collapse (Figures 4.2 and 4.3). The inland two lanes were passable at the time of this inspection trip.

Some of the access roads north and several feet above U. S. 90 from Gulfport west were destroyed by water erosion.

4.2 UTILITIES

Damage to overhead lines was caused almost entirely by trees and other debris falling on the lines and poles. The poles themselves were only very rarely blown over from the wind directly. Many poles away from trees can be seen standing in Figures 3.14, 3.18, and 3.24.

Some gas mains along U. S. 90 were uncovered by water erosion. Telephone, electric, and gas service were all knocked out by the storm over large areas. The loss of the primary power supply also slowed restoration of water and other services. Numerous operating gasoline-powered generators with OCD markings were seen by the inspection team, especially in the Pass Christian-Long Beach area.

Many gas and water lines were broken in damaged or destroyed buildings and had to be shut off from the lines before these services could be restored.

4.3 SANITATION

Waste water along with storm runoff and sea water was standing on U. S. 90 in several locations where storm drains were clogged with sand.

The local water supplies were not functioning or were contaminated after the storm. In some cases, water and sewage treatment plants were heavily damaged.

The team noticed that the debris from grocery store meat and produce counters was a serious sanitation problem not yet attended to at the time of this inspection trip. The odors from spoiled contents in refrigerators and freezers located in the debris also caused a problem as sometimes it was first thought that these were from the bodies of buried storm victims.

4.4 TREES AND AGRICULTURE

Much of the land in southern Mississippi is in forests and farms. Tung and pecan orchards were extensively damaged. Nearly all such trees were down as far north as the Hattiesburg area. Figure 4.4 shows a group of tung trees near Purvis.

An estimated 15 to 20 percent of the pine trees in the coastal counties were blown over, with smaller amounts farther inland. Corn crops as far north as Hattiesburg were completely flattened.

Much damage to structures and utilities and the blocking of many roads resulted from tree and branch blowdown.



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Figure 4.1 U. S. Highway 90 west of Bay Saint Louis.



Figure 4.2 U. S. 90 near west end of Pass Christian (east-bound lanes).



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Figure 4.3 U. S. 90 near Pass Christian.



Figure 4.4 Aerial view of damaged tung trees near Purvis, Mississippi.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY

Very extensive structural damage was done by Hurricane Camille both in the Mississippi River Delta area of Louisiana and in southern Mississippi. Wind velocities and tides higher than any previously recorded in the Gulf Coast area accompanied the storm.

The most intense areas of destruction were immediately adjacent to the Gulf of Mexico and appeared to have resulted primarily from water and wind-driven wave action. Any evidence of direct wind damage in these areas was usually destroyed by the water damage. It is believed that much of the damage in coastal areas could have been prevented only with very heavy construction, very restrictive zoning, by an enormous seawall, or by constructing all buildings with the first floor open, none of which are particularly practical or economical alternatives. The loads acting on many buildings were obviously larger than the design loads for the structures.

Wind damage to structures inland was small compared to that in the immediate coastal areas and less than had been expected.

The only structural damage seen to NFSS spaces was to those located in buildings very close to the seacoast (within the first few blocks). Some others farther inland had water damage to contents.

Tree fall due to wind was a great problem, especially with regard to transportation and utility systems. Chain saws were in very great demand in the storm area. A very significant portion of the structural damage away from the areas of water damage was caused by trees and branches falling onto buildings.

Masonry block structures proved particularly weak in the areas immediately adjacent to the Gulf where wave action was appreciable.

Mobile homes were heavily damaged both along the coast and inland.

Several examples of inadequate and/or faulty connections and construction details were seen.

5.2 CONCLUSIONS

The magnitudes, types, and durations of the loads acting upon the structures in the storm area are known only approximately. In many cases immediately along the seacoast, it appeared that wind was the critical loading on roofs and upper floors, while water and wave-generated loads were probably critical nearer the ground.

Because of the unknown loading histories, detailed analysis of the structures to obtain meaningful quantitative information concerning the strength and performance of the buildings located in the storm area will be most difficult. The storm damage did yield meaningful information on the weak points of buildings, the collapse mechanisms, and the relative strengths of various building types.

Three general conclusions reached concerning the performance of structures during this storm are:

1. Many buildings, especially masonry structures, are much too dependent on vertical forces (including deadweight) for their stability and have little strength when the loading is not vertical (lateral loads).
2. The connections and details so necessary in tying a structure together are too often inadequate. This can result from both inadequate design and poor construction.
3. The possibility of hurricane-caused loadings, even from storms much smaller in intensity than Camille, did not appear to have been recognized in the design of a great number of the more recent buildings constructed along the Gulf Coast.

The maximum 190-mph winds in the storm area correspond to a pressure loading of 0.8 to 0.9 psi. The storm damage cannot, however, be directly compared with that to be expected at this pressure level of a nuclear blast. First, much of the storm damage was caused by moving water or by water and wind in combination. This type of loading generally would not accompany blast loading. Second, several important loading phenomena accompanying a nuclear blast, especially the overpressure (or diffraction) loading with its nearly instantaneous rise time and any ground motion, were absent. The wind loading resulting from the storm corresponds only to the dynamic (wind) pressure loading phase of the loading from a nuclear blast.

5.3 RECOMMENDATIONS

More attention should be given to construction details and inspection. In many cases, more attention to these "small" items would greatly increase the structural strength with little additional cost. High-quality inspection during construction should, of course, be encouraged.

Masonry walls should be required to contain some reinforcement, especially in the bottom-story walls of construction located near coastlines. The use of masonry bearing walls in construction near coastlines with a hurricane history may need to be controlled (building codes).

Roof trusses and bar joists should be adequately connected at their ends to the supporting element. Use of very small or tack welds should not be permitted. Setting of trusses and joists only into masonry walls should be discouraged. Trusses, frames, and joists should be given adequate lateral support.

Well written and rigidly enforced building codes are needed in areas of potential storm damage to help prevent appreciable damage from most tropical storms and to minimize damage from unusual storms such as Camille. It should be realized, however, that it is most probably not economically feasible to require all buildings along the Gulf and lower Atlantic coastlines to be constructed so that they can survive undamaged such intense storms as Camille.

It is of direct interest to OCD and to the engineering profession to encourage the writing, adoption, and enforcement of building codes which will increase the inherent strength of construction, especially against lateral loads. Much construction can be feasibly "slanted" toward increased blast resistance by OCD only in this way. The structural adequacy of conventional construction will greatly affect the survival of structures and any occupants in the 1/2- to 5-psi overpressure zone of a possible nuclear detonation.

REFERENCES

1. R. M. DeAngelis; "Hurricane Camille - August 14-22, 1969"; Weekly Weather and Crop Bulletin, 1 Sept 1969, Vol. 56, No. 35; U. S. Weather Bureau, Washington, D. C.; Unclassified.
2. K. V. Wilson and J. W. Hudson; "Hurricane Camille Tidal Floods of August 1969"; U. S. Geological Survey, Hydrological Investigations, Atlas HA-395 through HA-408, 1969; Unclassified.
3. U. S. Weather Bureau, New Orleans; "Hurricane Camille . . . Gulf of Mexico . . . , August 14-18, 1969"; (Memorandum Report); Unclassified.
4. Committee Report; "Wind Forces on Structures"; Task Committee on Wind Forces, Committee on Loads and Stresses, Structural Division; Transactions, ASCE, 1961, Vol. 126, Part II, Pages 1124-1198; Unclassified.

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13. ABSTRACT This report describes the damage to structures seen by an inspection team sent to the Mississippi and Louisiana Gulf Coast regions after Hurricane Camille, a very violent but relatively small tropical storm, came ashore west of Gulfport, Mississippi, late on 17 August 1969. Many photographs of the storm damage are included. Extensive damage resulted both from the unusually high winds accompanying Camille and from the extremely high tides coupled with wind-driven waves. Damage was greatest in low areas immediately adjacent to the coastline. Because of uncertainties of the material properties for the various buildings and particularly of the loading, the report presents mainly qualitative results. More ductile buildings, such as heavy wooden frame construction, appeared to have survived the storm best. The storm damage indicated a need for more lateral strength in buildings, especially masonry structures, and for more adequate design of connections and other details.		

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